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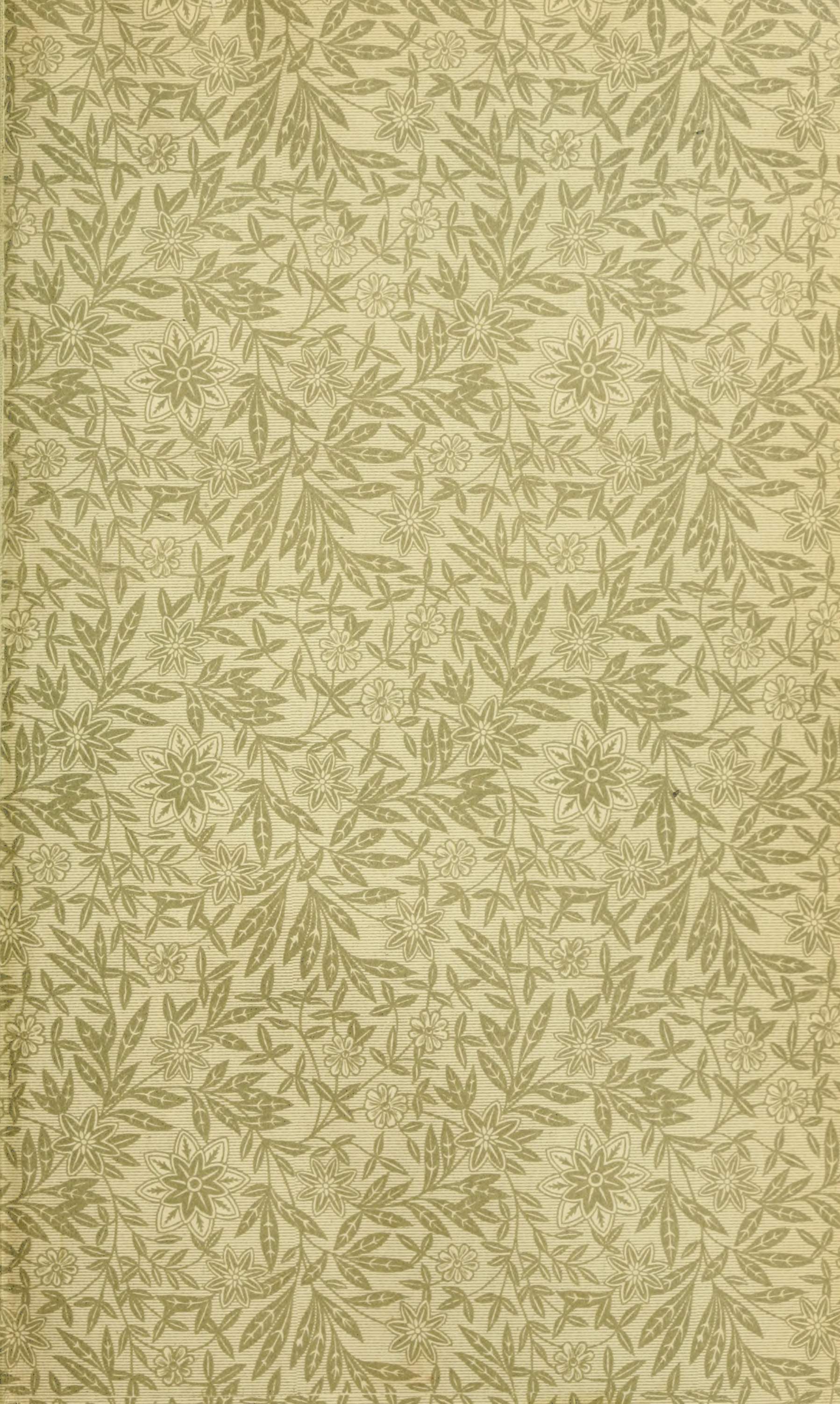

SECTION. DIVISION. BOOK.
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DYNAMO-ELECTRICITY:

ITS

GENERATION, APPLICATION, TRANSMISSION, STORAGE AND MEASUREMENT.

BY

GEORGE B.artlett PRESCOTT.

WITH 545 ILLUSTRATIONS.

8119

NEW YORK:
D. APPLETON & COMPANY.
1888.

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145
P88x

Entered, according to Act of Congress, in the year 1884, by

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PREFACE.

The evolution of the dynamo electric generator has practically given the world a new power; for although electric force or energy has long been known, and attempts have been made since the days of Volta, at the beginning of the present century, to employ it for obtaining and transmitting mechanical power, the only available source of this energy was, until lately, the galvanic battery, wherein electric currents are generated by dissolving zinc in suphuric acid, which is a very expensive source of power. To say nothing of the cost of the acid, the zinc—the very fuel of the battery—costs forty times more than coal, and is a far worse fuel; for, while an ounce of zinc will evolve heat to an amount equivalent to 113,000 foot pounds of work, an ounce of coal will furnish the equivalent of 695,000 foot pounds. Thus zinc gives in burning only one sixth of the effect in energy that coal does; and taking the difference in the cost of zinc and coal, the cost of energy in the case of a galvanic battery is 240 times greater than in a steam boiler. The discoveries of Faraday, Hjorth, Pacinotti and Gramme, which culminated in the evolution of the modern dynamo electric generator, have, however, supplied us with an economical source of electric energy, admirably adapted to many industrial purposes. To describe the various methods of generating, applying, measuring and storing this power, is the object which we have had in view in writing this work.

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DYNAMO-ELECTRICITY.

CHAPTER I.

PRODUCTION OF THE ELECTRIC LIGHT.

WHEN the terminal wires of a battery containing a number of cells are brought together, and then separated slightly, there results, as is well known, an intense, bright light between them, and to this, on account of its curved form, the name electric arc has been given. If the circuit is not immediately broken, the ends of the wires rapidly become heated, and, in a very short time, melt and drop off in glowing globules. Portions are even volatilized and pass off as vapor, whose color varies with the kind of metals employed, and with the medium in which the experiment is made. The distance between the ends consequently increases rapidly, and a point is soon reached at which the light is interrupted, the electro-motive force of the battery being then no longer sufficient to maintain a current against the opposing resistance. If, however, the wires are again brought together, and then separated as before, the arc is once more established, but, as we have just seen, it will last only for the very short time during which the electro-motive force is sufficient to overcome the resistance between the points.

When two pointed pieces of hard, conducting carbon are used for the terminals, as shown in figs. 1 & 2, the light becomes of dazzling brightness, too intense, by far, if the number of cells is considerable, to be carelessly regarded by the unprotected eye alone. By viewing it through colored glass, however, or by projecting an image of it upon a screen, it may be studied without danger.

As the number of cells is augmented, the light becomes not only more intense, but the arc may be materially lengthened, while its temperature, at the same time, is still further increased.

In the brilliant experiments of Davy, which were performed at the beginning of the present century, with some 2,000 cells of

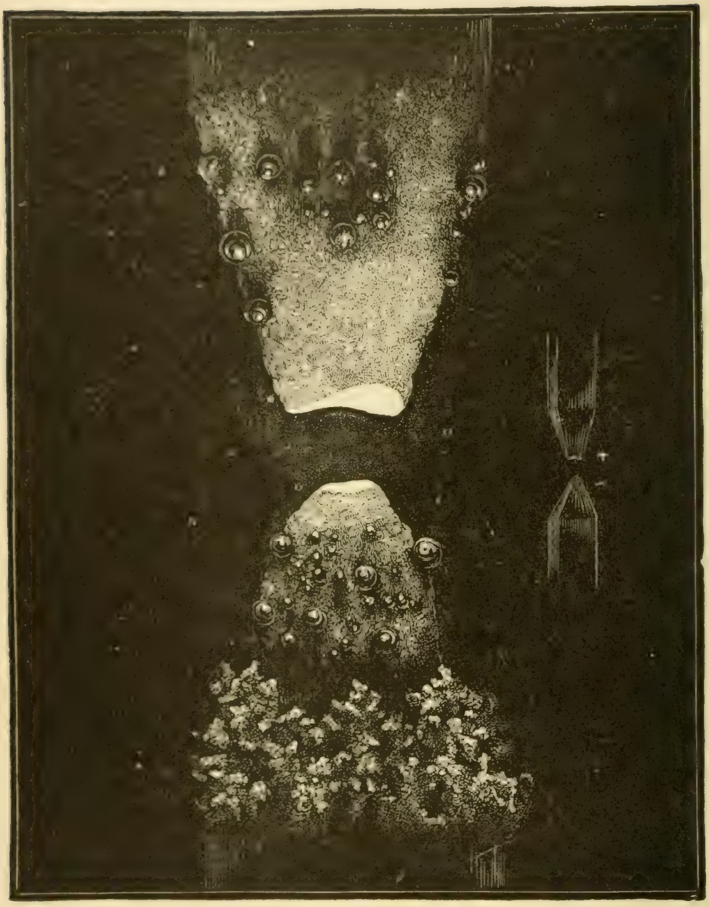

Fig. 1.

battery, and which were the first that were made on an extended scale, an arc of four inches in length was obtained in the open air, and in vacuo it increased to seven inches. Since then, more powerful elements, and greater numbers have been employed, and the resulting effects have been on a corresponding scale.

In temperature as well as brightness, the voltaic arc exceeds all other artificial sources of heat; by its means the most refractory substances are fused and volatilized, including even the diamond itself, which Despretz succeeded in reducing to vapor.

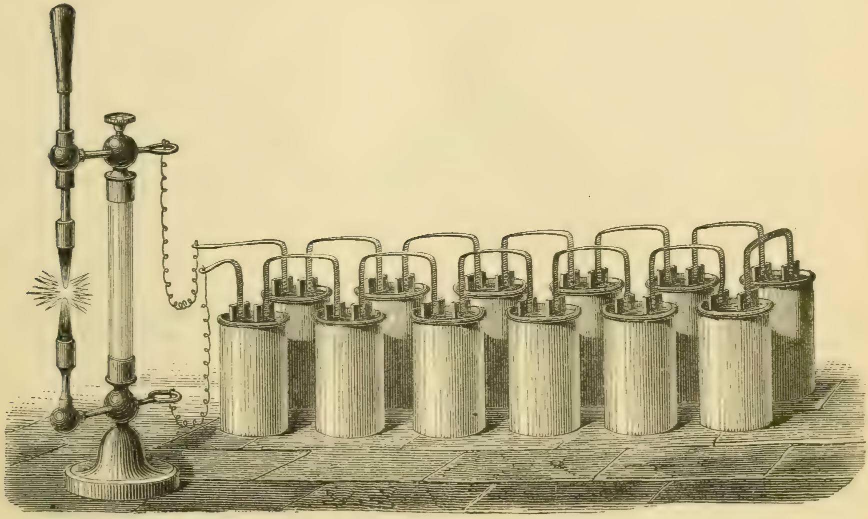

Fig. 2.

As the light continues, the positive carbon is found to waste away much more rapidly than the negative—a fact first observed by Silliman—and although the latter is first to become heated, its temperature in the end is less than that of the former, as may be seen when the light is interrupted, the positive carbon then continuing to glow for some time after the negative has become dark. In addition to this, it is also found that particles of the carbon are forcibly detached from the pencils and carried across the arc. This transport of particles can be rendered visible to a large number of persons at one time by throwing an image of the heated points upon a screen, with the aid of a lens. On watching the image for a few minutes, incandescent particles will be observed traversing the length of the arc, sometimes in one direction and sometimes in the other, the prevailing direction being, however, that of the positive current. This circumstance, which appears to be connected with the higher temperature of the positive terminal, explains the difference between the forms assumed by the two carbons. The point of the positive carbon becomes concave, while the negative remains pointed, and, as stated above, wears away less rapidly. In vacuo the difference is still more marked. A kind of cone then grows upon the negative carbon, while a conical cavity is formed in the positive.

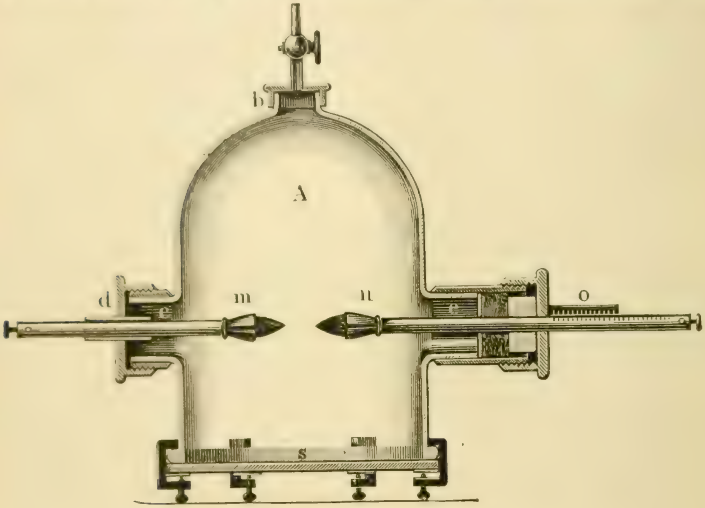

Fig. 3.

Fig. 3 shows a convenient apparatus for experimenting with the light in vacuo and in various gases. It consists of a bell shaped receiver of glass, provided with three tubular openings, two, *d* and *o*, opposite each other, and the third, *b*, on top.

To the latter is fitted a stop cock and tube, which serve for connecting the apparatus with the air pump, and also for introducing various gases when necessary. The other two serve to bring the two electrodes opposite each other, inside of the receiver, and are provided with tightly fitting caps through which the electrodes pass. The one over the opening *e* allows the electrode *n* to be pushed in or out at pleasure, and carries, besides, a scale *o*, by means of which the length of the arc may readily be ascertained. A ground glass plate, clamped to the bottom of the receiver, completes the details for rendering the apparatus air tight.

With the arrangement shown in figs. 2 and 3, the light, as we have already seen, is soon extinguished, owing to the increased distance between the points by the burning or wasting away of the carbons; consequently, when we require to use it continuously for any considerable length of time, it becomes necessary to employ some mechanical means for keeping the pencils at the right distance apart, or for bringing them together again automatically, if from any chance cause they should become separated sufficiently to cause the light to go out. A great many forms of apparatus have been devised for this purpose, some exceedingly simple, and others more or less complicated.

Fig. 4 shows a form of lamp devised by Duboscq, and operated by the combined action of the current and a system of wheel work, driven by a spring in connection with one of the wheels.

On a circular brass plate A, is mounted a metallic tube B, to which is attached the binding post C. A metallic rod D, sliding in this tube, carries at its top the arm E, to which is also attached a rod and socket for holding the upper carbon. This rod is arranged to slide in the arm E, so that it may be moved up or down for a limited distance, and is held tightly in any position that may be given to it. The lower end of the rod D is provided with a rack F, which engages with the wheel G, and the latter again is pressed on to the axis of another wheel H, and firmly held in place by friction. Within a barrel connected with wheel H there is a powerful spring, which serves as the motive force for actuating the mechanism of the lamp. A double rack J, terminating above in the rod O, which passes through an

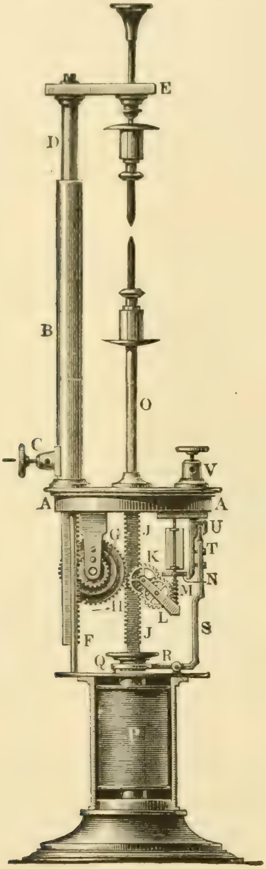

Fig. 4.

insulating guide in the cover, and is provided with a socket for holding the lower carbon, engages on one side with the wheel H, and on the other with the axis of wheel K. This wheel, in like manner, engages with the pinion of wheel L, better shown in fig. 5, and the latter again, with an endless screw M on the prolongation of the axis, carrying the cog wheel N and fly X. An electro-magnet P, consisting of a hollow iron tube, with its helix of insulated copper wire, is placed in the base of the lamp; and one end of the wire of the helix is connected to the binding post V, insulated from the cover, the other to the lower end of the rack J, which moves up and down in the hollow of the core. A circular piece of iron Q, attached to the bent lever R S T, serves as an armature to the magnet, and when attracted by the latter, causes the pallet of the supplementary lever U, which is controlled by the long lever R S T, to catch in the wheel N, and thus arrest its motion and that of the train of wheels with which it is in connection. There is also a pin or rod in connection with the apparatus, that can be pushed in from the outside, and made to start or stop the train work when desired.

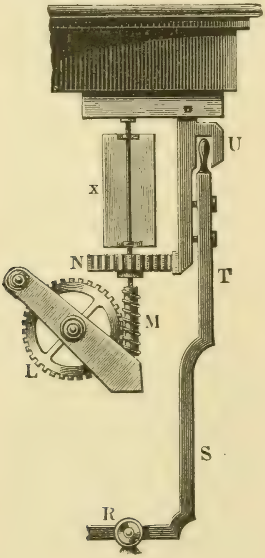

Fig. 5.

When the lamp is to be used, the rod D is raised. This causes the wheels G and H to revolve, and thus at the same time lowers the rod O, so that the carbons can be inserted. If allowed to act now, the spring within the barrel connected with H will cause the carbons to approach and touch each other. The battery can then be connected; the positive pole to the post V, the negative to C. With the passage of the current through the coil surrounding the core, the armature will be attracted and the train thus locked; but the points may be properly separated again by raising the rod carrying the upper carbon, and the light will then shine out in all its brilliancy. As the carbons burn away the current necessarily becomes weaker, on account of the increased resistance of the arc, and a time soon comes when the magnet is no longer strong enough to retain the armature. The retractile spring then prevails, and releases the wheel N, and thus allows the spring in the barrel of H to act and bring the points once more near each other. With the decrease in the distance between the points, the current becomes stronger and the armature is again attracted. A moment more, it is again released and again attracted, and so its position continues to vary from time to time with the changes in the strength of the current. It therefore becomes possible, by the use of the lamp, to maintain the light for a very long time without interruption. As will be observed, the diameter of wheel H is double that of wheel G, and consequently the carbon connected with the holder O moves through twice the distance of that in the upper holder. The object of this is to compensate for the more rapid wasting away of the positive carbon, which, as has been found, consumes about twice as fast as the negative. The use of wheels of different diameters thus furnishes the means for keeping the light at a given point, which is a matter of considerable importance in almost all of the uses to which it is applied; and when a reflector is used, is absolutely necessary, as otherwise it would be all but impossible to keep the light properly focused.

Fig. 6 shows another form of lamp, devised by Foucault. In this there are two systems of wheel work, one for bringing the

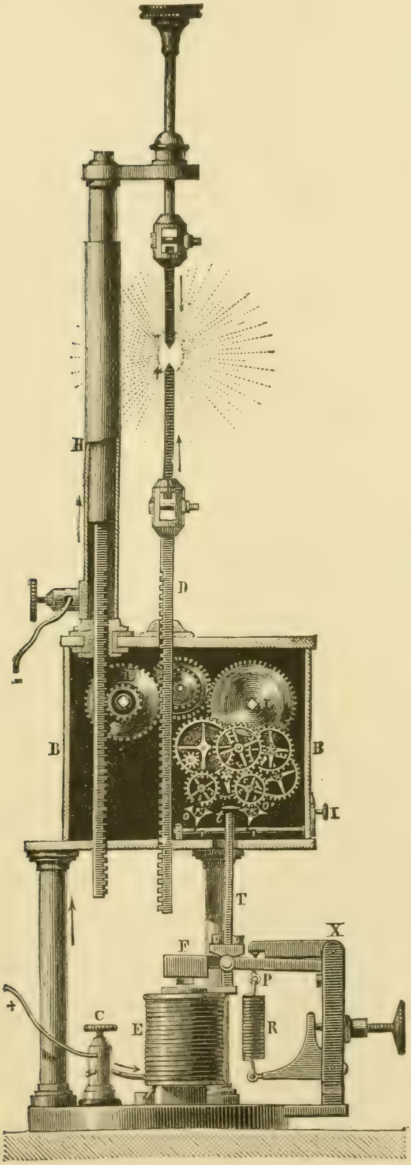

Fig. 6.

carbons together and the other for separating them, and it is principally in the addition of this last arrangement that the lamp differs from that of Duboscq, there being, in the latter form, no provision for automatically relighting the lamp in case it should accidentally go out. L′ is a barrel driven by a spring inclosed within it, and driving several intermediate wheels, which transmit its motion to fly *o*. L is the second barrel, driven by a stronger spring, and driving in like manner the fly *o*′. The racks which carry the carbons work with toothed wheels attached to the barrel L′, the wheel for the positive carbon having double the diameter of the other, the same as in the Duboscq lamp. The current enters at the binding screw C, on the base of the apparatus, traverses the coil of the electro-magnet E, and passes through the wheel work to the rack D, which carries the positive carbon. From the positive carbon it passes through the voltaic arc to the negative carbon, and thence, through the support H, to the binding screw connected with the negative pole of the battery. When the armature F descends toward the magnet, the other arm of the lever F P is raised, and this movement is resisted by the spiral spring R, which, however, is not attached to the lever in question, but to the end of another lever, pressing on its upper side and movable about the point X. The lower side of this lever is curved, so that its point of contact with the first lever changes, giving the spring greater or less leverage, according to the strength of the current. In virtue of this arrangement, which is due to Robert Houdin, the armature, instead of being placed in one or the other of two positions, as in the ordinary forms of apparatus, has its position accurately regulated, according to the strength of the current. The anchor T *t* is rigidly connected with the lever F P, and follows its oscillations. If the current becomes too weak, the head *t* moves to the right, stops the fly *o*′ and releases *o*, which accordingly revolves, and the carbons are moved forward. If the current becomes too strong, *o* is stopped, *o*′ is released, and the carbons are drawn back. When the anchor T *t* is exactly vertical, both flies are arrested, and the carbons remain stationary. The curvature of the lever on which the spring acts being very slight, the oscillations of the armature and anchor are small, and very slight changes in the strength of the current and brilliancy of the light are immediately corrected.

Mr. Hart, of Edinburgh, Scotland, has invented a simple lamp, in which the weight of the rod in which the carbon is fixed supplies the place of the clock work in the lamp just described, and an electro-magnet lets it descend, or locks it, as the carbons are consumed.

Mr. Farmer, of Newport, R. I., has also invented an automatic lamp, containing but little train work, and whose action is controlled by a regulator or relay, consisting of an axial magnet, the coils of which are placed either directly in the main circuit or in a branch of the same, and a delicately poised lever, from one end of which the axis bar of the coil is suspended. The action of the current, when too strong, tips the bar in one direction, and when too weak a retractile spring tips it in the other. It is the employment of this relay to operate the mechanism of the lamp, through the intervention of local or branch circuits, which constitutes the principal difference between this and most of the other forms of lamps now in use. The train of wheel work, driven by a spring, tends to cause the carbons to approach each other, but the motion is arrested if the armature of a small electro-magnet, forming part of the apparatus, is attracted. The tilting bar of the regulator closes the local circuit of this releasing magnet whenever the current is of the proper strength, but as soon as the current weakens, by the burning away of the points, the retractile spring of the regulator causes the lever to open the branch circuit of the releasing magnet, and the armature of the latter then allows the train to move. The carbons, consequently, approach each other until the main current again becomes of such strength that the regulator closes the branch circuit of the detaining magnet, and thus, once more, stops the motion of the train.

When the points run into actual contact, after the arc has been broken, the light is again established by a third electro-magnet, also in the main circuit, which withdraws the lower carbon from contact with the upper, and holds it in position until the arc is again broken. The movement of the carbon holders is caused by the action of two screws so geared together that one pencil, the positive, moves twice as rapidly as the other.

There are, besides, conveniences attached to each of the carbon pencil-holders, so that they can be disengaged from the screws and moved independently to any required position at pleasure. The holders, also, admit of separate adjustments on a vertical axis, so that by this means the carbons can be placed in a perpendicular line, one above the other. The spring does not need rewinding oftener than new carbons are supplied, and the performance of the lamp is very satisfactory. It has been run for hours when required, and no reason exists why it should not run continuously until the pencils are consumed, provided it be properly adjusted at first.

Within the last few years a new form of electric light apparatus has been introduced in France and elsewhere, which, from the remarkable properties that have been attributed to it, has attracted a great deal of attention. The invention is due to M. Jablochkoff, a Russian engineer, and is known as Jablochkoff's candle. It consists of two carbons placed side by side, and separated by an insulating and fusible substance. No clock work whatever is required, and the light is very soft and steady. Fig. 7 shows the arrangement as originally designed. The carbons *a*, *b*, some four inches in length and one quarter of an inch square, are imbedded in an insulating substance, *c;* the carbon slips being also separated from each other some three sixteenths of an inch, and the whole moulded into the shape of a candle. In order to facilitate the early action of the current, a small piece of carbon, about the size of the lead of an ordinary lead pencil, is placed across the top of the electrodes. A series of experiments with candles of this description were carried out at Chatham some time since, and, it is stated, the power then obtained was some fifty per cent. greater than that obtained previously from the recognized electric light.

Since then, M. Jablochkoff has twice modified this arrangement, each modification being attended with success beyond that obtained by the preceding. His first proceeding was to divest the carbons of their outer covering, leaving nothing but the carbon slips *a*, *b* (fig. 8), and the intervening substance, kaoline, *c*. Each carbon is fixed in a small brass tube *d*, *e*, the lower portions of which are left vacant, so that they may fit over two metal pins, attached to which are the wires from the magneto machine. These tubes are insulated one from the other, and the whole bound together by a band of insulating material *f*.

The latest modification embraces the removal of the carbons and the replacement of them by a carbon paste, a sort of priming, the object of which is to reduce the resistance which the kaoline, when cold, interposes to the passage of the current. With this arrangement a splendid band of light, constant, soft and steady, is obtained.

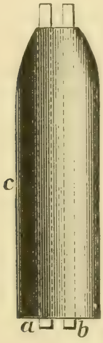

Fig. 7.

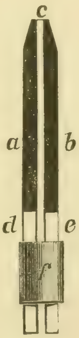

Fig. 8.

The principal advantages of the candle appear to be due to the fact that it is neither dazzling nor blazing, and does not, therefore, surround the various objects illuminated with the disagreeable haze and ghastly shadows that are observed when the ordinary electric light is used. It is, however, somewhat more expensive, but, as a compensation, is said to allow of a greater subdivision of the current—as many as fifty lights having been maintained from a single source by its use.

A novelty in electric lamps has just been brought out by Mr. Wallace, and, we learn, will soon be placed in the market at a very low figure. It consists principally of a substantial metallic frame and an electro-magnet. There are two slides in the frame, each capable of holding, in a horizontal position, the two carbons, which are made in the form of plates, twelve inches long by two and a half wide, and half an inch thick. The upper and lower parts of the framework are insulated from each other, and in electrical connection with two binding posts, on the upper part, serving to connect them with the magneto machine. The electro-magnet, through whose helices the main current circulates, is placed in the centre of the frame above the carbons, and, by its action on an armature, serves to separate the upper carbon from the lower, to any distance desired.

When the lamp is joined with a magneto machine by means of the binding posts and conducting wires, the circuit is completed through the carbons, which touch each other, and the armature is attracted, thus separating and holding them apart so long as the current is maintained. The light burns toward the opposite end from which it started, then changes and burns back again, always burning toward the place where the carbons are nearest. If, from any cause, the light goes out, the circuit is broken, and, of course, the electro-magnet ceases to act. But the instant the upper carbon falls the circuit is again closed, and the carbons are once more separated and relighted.

The advantages of this lamp are that it contains no combination of wheels or springs, and, consequently, there is no winding up of the apparatus to look after. The carbons, again, are so large that they will last for ten nights, of ten hours each, and the lamp requires no care except for their renewal. The practical disadvantage that suggests itself is its lack of means for maintaining the light at a given point, so as to use it in connection with a reflector.

Figs. 9 and 10 show two forms of the Brush electric lamp, as manufactured by the Telegraph Supply Company, of Cleveland. Fig. 9 is a hanging lamp, intended for factory use; fig. 10 an adjustable table lamp.

There are also a great many other lamps, such as Serrin's, Browning's, Siemens's, etc., and all of which are more or less employed when it is desired to maintain the constancy of the light for long continuous working; but the apparatus we have just described contain most of the principal characteristics and conveniences embodied in these, and it will, therefore, be unnecessary to give more attention to this part of the subject at present.

Instead of the battery, whose employment for light purposes is now almost exclusively confined to the illustration of lecture-room experiments, and physical demonstrations in class rooms, or to the production of luminous effects in theatrical exhibitions —places where it is seldom convenient to employ a steam engine—dynamo electric machines are now almost universally used, and their advantages over the battery are very marked in a great many particulars. Of late years, dynamo machines have also been extensively introduced in electro plating establishments, to take the place of batteries, but in such cases their construction is considerably modified, in order to adapt them to this particular kind of work. As ordinarily constructed for light purposes, the machines would have an electro motive force far too high for plating, where, as a general thing, two or three volts are all that are required.

Large dynamo electric machines, for light purposes, appear to have been first suggested by Professor Nollet, of Brussels, in 1850, but since then a great many modifications and improvements have been introduced, so that the machines of to-day, although depending for their action, like the earlier ones, upon the same inductive principle by which mechanical force is transformed into electricity, are nevertheless far superior to them, both as regards economy and effectiveness when in action.

Fig. 11 represents one of the first forms of these machines as constructed by Holmes, of London, and the Compagnie l'Alliance,

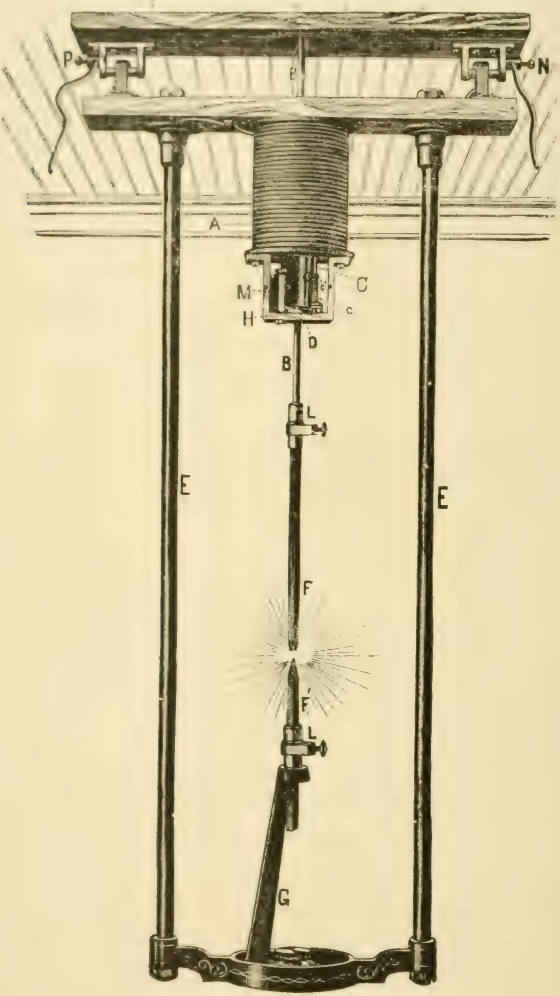

Fig. 9.

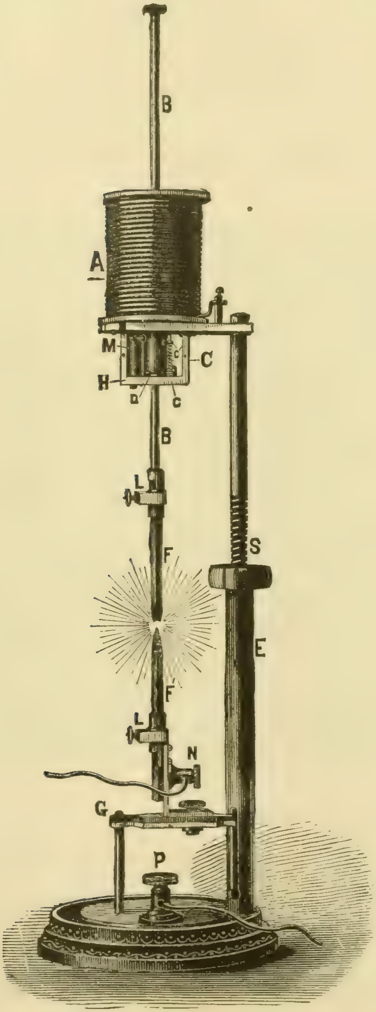

Fig. 10.

of Paris, and which at one time promised to become of very extensive application for light-house purposes.

In this machine there are eight rows of compound horseshoe magnets fixed symmetrically around a cast iron frame. They are so arranged that the opposite poles always succeed each other, both in each row and in each circular set. There are also seven of these circular sets, with six intervening spaces. Six bronze wheels, mounted on one central axis, revolve in these intervals, the axis being driven by steam power, transmitted by a pulley and belt. The speed of rotation is usually 350 revolutions of the axis per minute. Each of the six bronze wheels carries, at its circumference, sixteen coils, corresponding to the number of poles in each circular set. The core of each coil is a cleft tube of soft iron, this form having been found peculiarly favorable to rapid demagnetization. Each core has its magnetism reversed sixteen times in each revolution, by the influence of the sixteen succes-

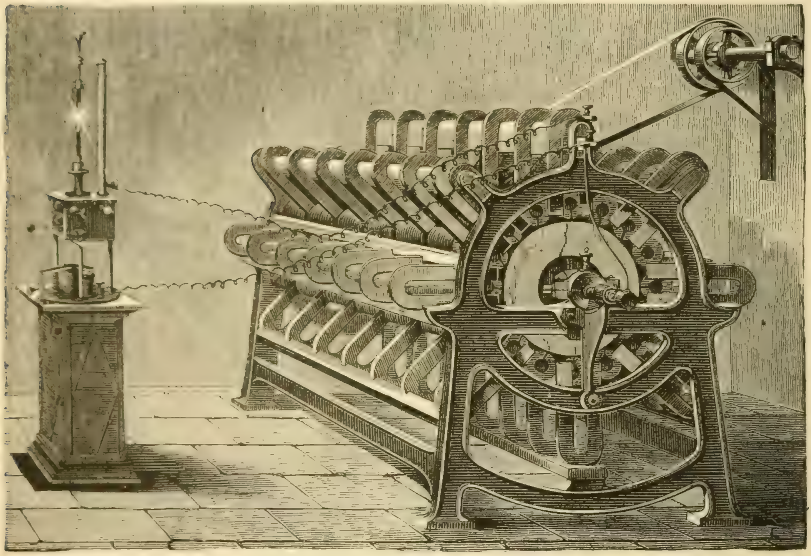

Fig. 11.

sive pairs of poles between which it passes; and the same number of currents, in alternately opposite directions, are generated in the coils. The coils can be connected in different ways, according as great electro-motive force or small resistance is required. The positive ends are connected with the axis of the machine, which thus serves as the positive electrode; and a concentric cylinder, well insulated from it, is employed as the negative electrode.

In 1854 Siemens devised a very effective armature, which has since been much employed by other manufacturers in different forms of machines. The principal advantage of this armature results from its occupying but little space for rotation. Consequently, it can be kept in a very strong magnetic field; at the same time also its form renders it well adapted for rotation. It consists of a peculiarly shaped electro-magnet, such as would be formed by cutting two wide and deep longitudinal grooves opposite each other in a cylindrical bar of iron, and then continuing them around the ends. The wire is wound lengthwise around the core in the groove, like thread upon a shuttle, and brass caps, provided with axes and a pulley, are then screwed on to the ends of the magnet. When this armature is mounted between the poles of a series of permanent horseshoe magnets and rotated rapidly, very strong currents are produced. The two ends of the wire are connected with a commutator, formed by fastening two semicircular pieces of brass to an ivory ring on the axis, and springs bearing upon these brass pieces, and in metallic connection with the binding posts of the apparatus, supply the means for collecting and conducting away the electricity produced in the wire coils.

By employing two of these armatures and taking advantage of the property which soft iron possesses of receiving a much higher degree of magnetism than steel, and consequently, therefore, of its capability of producing stronger currents by induction in movable coils within its field, Mr. Wilde, of Manchester, England, has succeeded in constructing very energetic machines, and which are well adapted for producing the electric light.

The apparatus in reality consists of two machines combined in one. The current from one of the Siemens's armatures, produced by its rapid rotation in the strong magnetic field of a series of permanent magnets, is employed to charge a large and powerful electro-magnet, between whose poles the second armature is made to revolve, and the current from the latter is utilized for the light.

Two armatures for the electro-magnet are sometimes furnished with the machine, one with wire coils for the production of currents of rather high electro-motive force, to be used for light purposes alone, and the other with coils of sheet copper strips, which give currents of less electro-motive force, but more especially adapted for plating. With the interchangeable armatures, which are driven by belts running on pulleys on their axis, the machines can be used either for lighting or for plating at pleasure, and this, in some particular cases, is a very desirable feature.

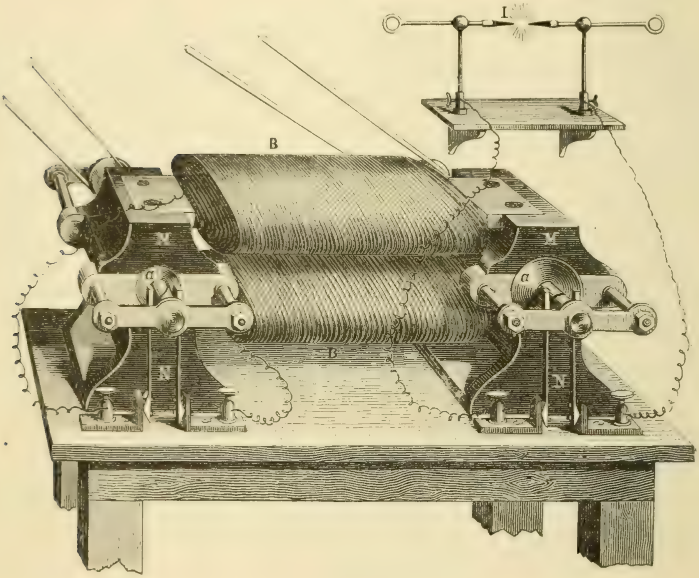

Fig. 12.

Numerous other machines are constructed with interchangeable armatures, on the same plan and for the same purpose.

Another form of magneto apparatus is that known, from the name of its inventor, as the Ladd machine. This was first publicly exhibited at the Paris Exposition of 1867. It is shown in fig. 12, and, as will be seen, employs, like the Wilde machine, two Siemens's armatures, but it differs from the latter principally in not having any permanent magnets whatever to charge the armature which supplies the horizontal field coils B B. Two long flat pieces of soft iron are placed within these coils and attached to the iron castings or pole pieces MM, NN, which are turned out just large enough for the armatures to fit inside of them and rotate without touching. Thick strips of brass or other non-magnetic metal are also placed between the upper and lower castings M and N, to keep them separate from each other, and thus subject the armatures between them to the full force of their inductive action.

The connections of the coils are such as to produce opposite polarities in M and N; and the armature at the left of the machine supplies the field coils, while that at the right furnishes the current for the light.

One of the most remarkable properties of these machines is that by virtue of which they become capable of producing exceedingly powerful currents from the smallest beginnings; the simple reactive effect of the very slight residual magnetism that remains in the cores after they have once been charged being, in fact, all that is required, on revolving the armatures, for their production; and to operate a new machine, it is only necessary to place it in such a way that the armatures will stand in the magnetic meridian, and then cause the one which supplies the field coils to rotate rapidly. This, of course, causes the convolutions of wire surrounding the latter to cut through the lines of force due to terrestrial magnetism, and produces in them electrical currents of greater or less magnitude, depending upon their velocity of rotation, which, on traversing the larger coils B B, render the cores and pole pieces M N slightly magnetic. The reactive effect of the magnetism in the pole pieces on the armature is thus added to that produced by the earth's magnetism, and an increased current flows into the field coils. A greater degree of magnetism is consequently produced in the pole pieces, which causes the latter to react once more on the armatures, and the result of which is a corresponding increase in the current, and increased magnetism. By this means, therefore, the current, in an exceedingly brief interval of time, increases from nothing to a maximum of strength, at which it remains practically constant for a uniform velocity of armature rotation. It is usually better, however, and much more convenient in charging a machine for the first time, to use the current from a battery, or from another machine already charged, than to depend alone, for this effect, upon terrestrial magnetism.

The machines thus far described furnish only momentary currents of varying strength and polarity. If currents of but one direction are required, these intermittent currents must be rectified, as we have already seen, by means of a commutator, and this causes a diminution in the strength of current, and is frequently accompanied by the production of sparks. Mr. Z. J. Gramme has, however, invented a machine in which these objections are not met with, as the current obtained from it flows continuously, and in one direction only.

The magnetic field in this, as in other machines, is created by a powerful magnet, of such a shape that its poles confront each other, and its characteristic feature, therefore, lies wholly in the construction of the armature. This consists of a ring of soft iron, surrounded by an endless coil of wire, and is rigidly attached to an axis, so that it can be made to revolve ; one half of the ring being under the influence of the north pole, and the other under that of the south pole of the magnet.

As the ring revolves, every portion of it changes position in the magnetic field ; but no current is developed in the wire, considered as a whole, as the latter entirely surrounds the ring, and the magnetic state of this, as a whole, remains unchanged. A point on the ring considered by itself, however, changes polarity twice during every revolution. As it recedes from one pole, it generates in the surrounding wire an electro motive force, the same as that generated when it approaches the other pole, and the two electro motive forces, consequently, oppose each other, but whenever an external conductor is provided between them, they unite and produce a current.

In practice, the ring consists of a bundle of soft iron wire, and the helix is made in sections, each one of which is connected to its neighbor, and also to a strip of brass forming the means of connecting with the external circuit. During a revolution, and when the electro motive forces of opposite sections are at a maximum, the corresponding brass strips touch a couple of metallic springs, and thus make connection with the external conductor. The peculiar construction of the ring will be seen by referring to fig. 13, where several sections of the wire B B are shown upon the ring A. The figure also shows the way in which connection is made with the brass strips R.

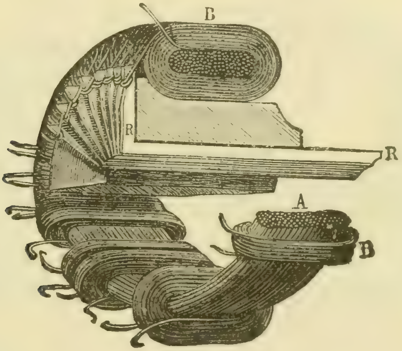

Fig. 13.

A convenient form of the Gramme machine, constructed especially for the laboratory and lecture table, is shown in fig. 14.

At the present time electric light machines and machines for plating purposes are made by numerous manufacturers in this country; but formerly by none on a scale so large as that carried on by Messrs. Wallace & Sons, of Ansonia, Conn. This firm began the construction of these machines for the market in the spring of 1875, and since that time there is hardly any form of magneto machine that has not been built and tested at their works.

The machine which they finally decided upon manufacturing, as possessing the greatest merit, is the invention of Moses G. Farmer, formerly of Boston, but now and for the last three years electrician at the Government Torpedo Station, at Newport, R. I.

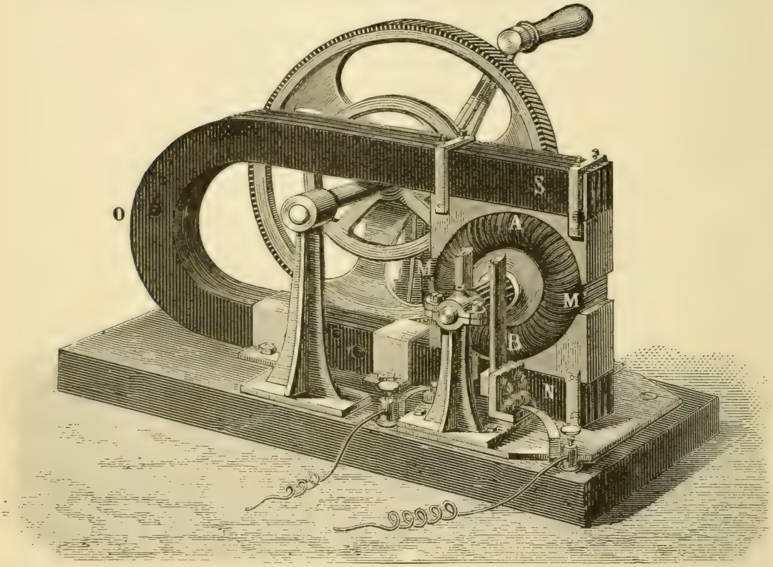

Fig. 14.

This machine, which has been somewhat modified and improved upon from time to time by Mr. William Wallace, is, in many respects, unlike any of the other forms that we have considered. It consists of two large electro-magnets, an armature, two commutators and four brushes, the latter forming part of the circuit, and serving, when the machine is in operation, to collect the currents generated in the armature coils. The two magnets are mounted upon a cast iron frame, similar to that of a lathe, and are made to face each other, while the armature, which consists of an iron casting of varying diameter, according to the size of the machine, is mounted upon a shaft, and placed between the magnets. The shaft also carries pulleys at each of its ends, and is made to rest in bearings in the yokes of the electro-magnets. The armature disk carries on each side, and near its periphery, twenty-five wedge shaped projections, of which there are fifty in all, that face the poles of the electro-magnets, and on which coils of wire are placed. The terminals of these coils are joined together, and a wire, connected with the junctions, leads to the commutator, situated on the same side of the plate—all the coils on one side connecting with one commutator and all on the opposite side with the other.

The commutators are placed upon the shaft, between the legs of the two magnets, and consist of wood or other more durable insulating substance, on which strips of brass, connecting with the wires from the armature coils, are secured. The connections of the machine are so arranged that when the external circuit, which may consist of the light apparatus or depositing vats with their leading wires, is completed, the armature and field of force coils are combined with it in one—an arrangement for which Mr. Farmer obtained a patent in 1872, and which, when the external resistance is low, is of very great advantage.

The eight inch machine, so called from the length of its electro-magnet, and which is the one most commonly employed, will produce two lights of about two thousand candle power each, and is so arranged that the two may be combined in one if desired. It weighs six hundred pounds, and requires to drive it about one horse power for every twelve hundred candle light.

The machines made by Messrs. Wallace & Sons weigh from one hundred and twenty-five to three thousand pounds each, and are capable of producing a light equal to that of from one thousand to forty thousand candles. Some of them will even maintain the arc with the carbons three and a half inches apart. Fig. 15 shows another form of the light machine, as constructed by the Telegraph Supply Co., of Cleveland, on a plan devised by Mr. C.

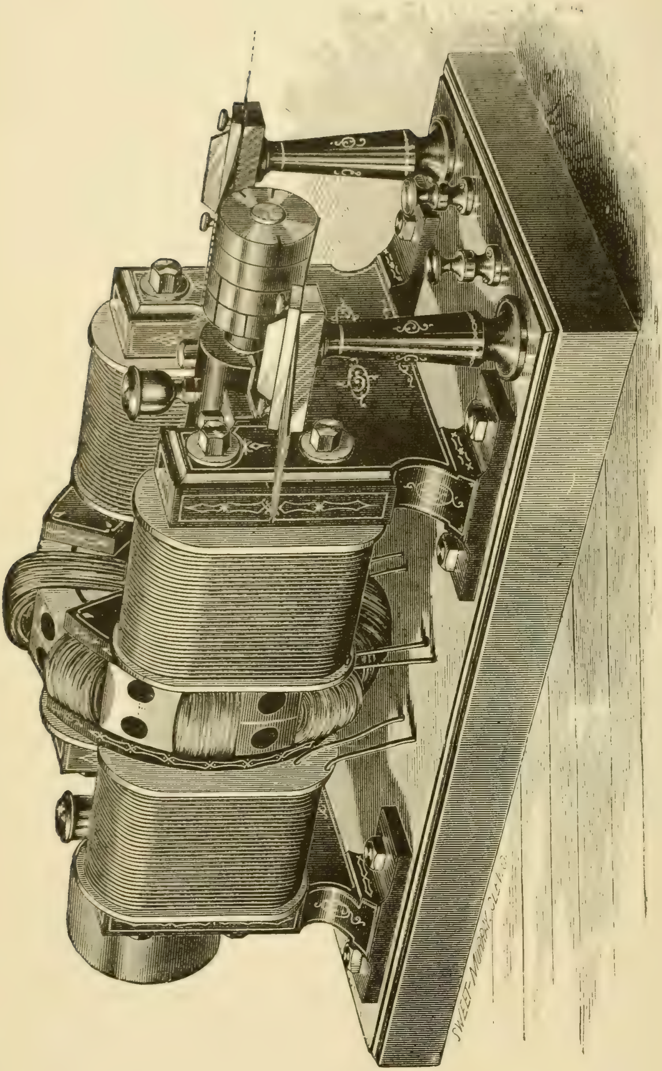
SWEET-MURRAY-CLARK SC.

Fig. 15.

F. Brush. There are two marked differences between this and other machines, the first of which consists in the peculiar method adopted for winding the armature; the latter is composed of a ring or endless band of iron, but instead of having a uniform cross section, like that of the Gramme machines, is provided with grooves or depressions whose direction is at right angles to its magnetic axis or length. These grooves, which may be of any suitable number, according to the uses for which the machine is designed, are wound full of insulated copper wire. The advantage of winding the wire in grooves or depressions in the armature is twofold; first, the projecting portions of the armature between the sections of wire may be made to revolve very close to the poles of the magnets from which the magnetic force is derived. By this means the inductive force of the magnets is utilized to a much greater extent than is possible in the case of annular armatures as ordinarily used, which are entirely covered with wire and cannot, therefore, be brought very near the magnets; second, owing to the exposure of a very considerable portion of the armature to the atmosphere, the heat, which is always developed by the rapidly succeeding magnetizations and demagnetizations of armatures in motion, is rapidly dissipated by radiation and convection. In the case of armatures entirely covered with wire the escape of the heat is very slow, so that they must run at a comparatively low rate of speed, with corresponding effect, in order to prevent injurious heating. The second difference lies in the manner of connecting the armature coils to the commutator, this being such that only the particular coils which contribute to the production of the current are in circuit at once. During the time they are passing through the neutral points in the magnetic field they are cut out one after the other, and thus, while idle, do not tend to weaken the effects of the machine by affording a path to divert the current generated in the active sections from its proper channel.

It would be an interesting matter, if the efficiency of all the different machines employed in the production of the electric light could be obtained and published, so as to be readily available. A general comparison could then be made which would, in a measure, settle the ever-recurring question in regard to the superiority of this or that machine. Undoubtedly, this information exists for many of the machines, as numerous measurements of them have been made by different experimenters, but the results have in most cases never been made public, and are, therefore, to be found only in the hands of the individual experimenters themselves. It may be stated, however, from such information as we have found available, that the amount of energy obtainable as electricity from the best machines probably does not exceed, or if so, only in a slight degree, two thirds that of the mechanical force required to drive them.

The expense of maintaining the electric light is much less than that incurred by the employment of any of the ordinary methods of illumination. Mr. Farmer states that where a large amount of light, say from five thousand to ten thousand candle light, is required, it can be produced from a suitable machine at the rate of one thousand candle light per horse power; but, smaller amounts—say two hundred to three hundred candle light—are relatively more expensive, probably about one half horse power for two hundred to two hundred and fifty candle light.

This is much more economical than when produced from any of the ordinary forms of galvanic battery. One horse power may be reckoned as costing from two to six cents per hour, which would give the cost of ten thousand candle light as sixty cents per hour, simply for power. Of course some other items, such as oil, attendance, interest and depreciation, also cost of carbons consumed, would increase this amount somewhat, but even at twice or three times this cost it is still much less expensive than gas light at three candle light to the cubic foot per hour, at $2.50 per thousand for gas.

The difficulty of procuring carbons that would burn uniformly has been a source of a great deal of annoyance. If the carbon is taken just as it comes from the gas retorts and sawed into shape, it is found to contain many impurities, and, when burning, will frequently split and large pieces drop off. If it is first pulverized and then pressed into shape, as is done for battery plates, difficulties of one form or another still appear, and the long road of trial and failure has generally had to be pretty well trodden over by all who have given this part of the subject much attention. Mr. Wallace, who has studied it very closely, has, we believe, succeeded in producing very satisfactory carbons, but we are, as yet, unacquainted with the process.

The best illuminating effect appears to be produced from thin carbon pencils, but it has heretofore been found impracticable to use such pencils, on account of their high resistance and the rapid consumption of material due to the action of the air on their highly heated ends. Mr. Brush has sought to obviate these difficulties, and at the same time improve the illuminating power of the light, by the admixture of different foreign substances with the carbon and by surrounding the stick either mechanically or by electro-plating with various metals. By this means a free and ready conductor is afforded for the current and a good connection between the carbon and its holder secured, while the employment of longer and thinner pencils is also rendered practicable, and there is little or no liability to breakage.

In operation the intense heat of the arc melts and disperses the covering of the carbon sticks at their opposing points and for a proper distance beyond, but no farther. The balance of the carbons is entirely preserved, while as fast as they are burned, just so fast will their covering be removed, leaving the carbons exposed.

The subdivision of the light is another of the problems that have occupied the attention of inventors a great deal. No one doubts that the division can be effected, but to do this in a simple manner, and offer to the public a cheap and practical device for the purpose, has not been an easy task. It would appear, from some of the latest experiments made at the works of Messrs. Wallace & Sons, that there is scarcely any limit to the number of subdivisions that can be made, and, to a certain extent, most of the machines are now constructed to give separate lights. One form of construction of the Brush machine is capable of producing four independent lights, of 3,000 candle power each.

One of the early methods of obtaining a number of lights from a single source consists in the employment of thin strips of platinum or iridium, whose temperature is raised by the passage of the current to a point only slightly below the melting point of these metals. When strips or wires of either metal are rendered incandescent, a mild and pleasant light is emitted, much less contracted and glaring than the light obtained from carbon pencils; and with the additional advantage also, that no vitiation of the atmosphere occurs, and the amount of light, at any one point, can be made as small as may be desired.

Platinum, according to Mr. Farmer, affords about 100 candle light per square inch of incandescent surface, when within 220° of the point of fusion, and a bar or wire of this metal can be maintained at this temperature for any length of time by means of a suitable regulator and current. Iridium is even better adapted for illuminating purposes than platinum, as, in consequence of its higher melting point, it yields more light per square inch of heated surface.

While it is undoubtedly true that the light obtained in this way is not the most advantageous for light house and steamship purposes, or for places where the dazzling light of the arc is required, it is none the less true that for many other, and especially for private or domestic uses, it possesses decided advantages over the carbon light, and on many accounts—among which the facility attending its regulation is not least—is far preferable.

CHAPTER II.

PROGRESS IN ELECTRIC LIGHTING.

The first chapter of this work is confined to a brief general idea of the production of the electric light and to the state of the art at the close of the year 1878. The second chapter is devoted to a reconsideration of the subject, and to the presentation of such additional information as will give the reader a comprehensive idea of the progress which was made in the application of electricity to lighting purposes during the succeeding two years. The third chapter describes the invention and development of incandescent electric lighting; and the succeeding chapters illustrate the enormous strides which have been made within the past few years, both in electric lighting and in the production and transmission of electric energy.

It has been stated, on page 30, that much difficulty is experienced in procuring proper carbon pencils for light purposes —a fact that any one who has at all experimented with electric lighting cannot have failed to notice; and it will, therefore, be interesting to say a few words first in regard to the best means that have been devised by different experimenters, in the preparation of material, for remedying this defect.

Foucault certainly made a decided step toward the practical use of the light when he substituted gas retort carbon for the substance previously used. Before that time the arc was scarcely more than an interesting toy, and only rarely seen outside of the cabinets of schools and colleges; but, as intimated, the substitution partook more of the nature of an improvement than anything else, and did not solve the question completely, since, to this day, it occupies the attention of practical men.

One of the earlier methods of preparing carbons, and which to some extent is still used, consists in first reducing coke to a very fine powder and mixing it with syrup with which it is thoroughly incorporated. The mixture is then strongly compressed in moulds and baked, and afterwards placed in a concentrated solution of sugar or molasses until saturated. It is then placed in an oven and raised to a white heat, at which it is maintained for an hour or more. By this means moisture is all driven off and a compact mass is formed, which may be rendered still more solid by repeated saturation and baking. The disadvantage of carbons prepared in this manner, however, is that they contain all the impurities of the coke, no means being taken to exclude these injurious matters.

A purer material, capable of giving a very steady light, is made by placing pencils of gas retort carbon in caustic potash or soda, melted and raised to a white heat, and in which they are allowed to remain a quarter of an hour or more. The sticks are then washed in hot water, and placed in a porcelain or refractory earthen tube, through which a current of chlorine is passed, while the whole is maintained at a red heat for several hours. Many of the impurities that are not removed by the potash or soda are thus changed into volatile chlorides and driven off.

Another way of procuring very pure carbons, according to M. Fontaine, from whom we borrow liberally on this point, has been suggested by M. Jacquelin, a French chemist, of the Central School, at Paris. This consists in imitating the condition of things that is brought about in gas retorts during the manufacture of gas, which is the reduction of the material and contact of the heated and very dense hydrocarbon matter with the sides of the retort. Part of the matter is thus volatilized, while the rest is decomposed, and leaves a deposit of carbon. In the retorts of gas works the hydrocarbon matters carry with them much of the impurities contained in the coal; but, by taking tar, produced by actual distillation, which is consequently free from all non-volatile impurities, and reproducing the above conditions in specially prepared apparatus, it would seem possible to produce carbon of great purity, and such has actually been found to be the case. Plates obtained in this manner, and sawed into sticks of the proper dimensions, give a perfectly steady light that is not only whiter, but more intense as well—something like twenty-five per cent. more so for a given current than that produced by carbons prepared in the ordinary manner. Considerable inconvenience, however, is experienced in preparing the sticks for use, as the carbon is so hard that it can only be cut with the greatest difficulty.

A composition for artificial carbons, consisting of powdered coke, calcined lamp black and a particular syrup formed of twelve parts of gum and thirty of cane sugar, has been introduced in France within a couple of years past, and is strongly recommended by the inventor, M. Carré. . The proportions given in his patent are, fifteen parts of the purest coke, reduced to a very fine powder; five parts lamp black, and seven to eight of the syrup. The whole should be thoroughly ground together, and one to three parts of water added to compensate for the loss by evaporation, and give it the degree of consistency which it is desired the paste should possess. The latter is then pressed and passed through a die plate, by which process the proper form is given to the carbons. These are afterwards packed in crucibles and subjected to a high temperature.

The baking of the carbons really comprehends a series of operations. In the first place, the drawn or moulded sticks, while yet soft, are placed in a horizontal position on a bed of coke dust, in crucibles, each layer being separated from its neighbor by a sheet of paper between them, so as to prevent adherence of one to the other. A layer of powdered coke, of about four tenths of an inch in thickness, is then placed on top, between the last series and the cover, and over the joint of the latter is spread a like thickness of silicious sand.

After the first baking, which should be continued at a cherry red heat for four or five hours at least, the carbons are taken out and placed in a vessel of boiling hot and very concentrated syrup of sugar cane, or caramel, and left for two or three hours, allowing, also, two or three cooling intervals of some duration, so that the pores may become filled. The carbons are then drained by opening a stop cock at the bottom of the vessel, and allowing the liquid to run out. They are then stirred a few moments in boiling water, to dissolve any sugar that may remain on the surface.

When dried, they are again replaced and baked once more, after which they may be packed in the crucible in a standing position, with sand between them, the above operation being repeated until they have acquired the density and solidity required. They are then dried slowly, the drying process being terminated in a drying oven, whose temperature gradually attains eighty degrees centigrade, in twelve or fifteen hours, and to prevent their change of shape in drying, the sticks are placed in V-shaped pieces of metal.

The Carré carbons are more tenacious and rigid than retort carbon, and are remarkably straight and regular. Sticks two fifths of an inch in diameter may be used, eighteen inches in length, without fear of breaking; and their cylindrical form, joined to their homogeneity, causes their ends to remain as perfectly sharpened as if they were turned. They are also better conductors than retort carbon. The only inconvenience that appears to accompany the use of carbons prepared in this manner, consists in their rapid wasting away, the production of small sparks and the irregularity of the luminous effect.

We learn from M. Fontaine's work, that the admixture of foreign substances with the carbon, of which mention has been made on page 31, has also been carefully studied by M. Carré, within a few years past, with very interesting results; and, from a large number of experiments made by him, he has been able to deduce the following important facts:

1. That potash and soda at least double the length of the arc, rendering it also free from the hissing sound so peculiar to it when carbon alone is used, while, at the same time, by combining with the silicates that are usually present, they eliminate these substances from the pencil points, causing them to fuse into clear, vitreous and often colorless globules just outside of the arc, and that they increase the illuminating power in the ratio of 1.23 to 1.

2. That lime, magnesia and strontium increase the light in the proportion of 1.40 to 1, and color it variously.

3. That iron and antimony enhance the illuminating effect to 1.60 and even to 1.70.

4. That boracic acid, forming a covering that excludes the material from the oxygen and the air, increases the durability of the carbon materially, though without augmenting the light.

Numerous experiments have also been made by M. Gaudoin with carbons containing borate, chloride, phosphate and silicate of lime, pure precipitated silex, borate of magnesia, magnesia, aluminum and silicate of aluminum, the proportions being calculated so as to give about five per cent. of oxide after the baking of the carbons; but, although the light is about double that obtained from gas retort carbons, the flame and vapor resulting from the use of carbons prepared in this manner, is, aside from the dangerous character of the fumes, a great obstacle to their practical introduction, and for this reason chemically pure carbons only should be employed where continuous light is desired.

The dust of retort carbon, although containing but a small proportion of foreign matters, is, nevertheless, not sufficiently pure for this use, and its employment presents some inconveniences, while washing in acids or alkalies, to which the carbonaceous matters may be submitted, with the aim of extracting the impurities they contain, is a costly and insufficient operation. Lamp black is pure enough, but its price is high and its management difficult.

M. Gaudoin, however, has found a solution of the problem in decomposing, by heat in closed vessels, the dried pitches, fats or liquids, tars, resins, bitumens, natural or artificial essences or oils, and other organic matters, capable of leaving behind sufficiently pure carbon after their decomposition by heat.

The apparatus employed for effecting this decomposition consists of closed retorts or crucibles of plumbago, and these are placed in a furnace capable of being heated to a bright red. The lower parts of the crucibles are furnished with two tubes, one serving for the disengagement of gas and volatile matters, and the other for the introduction of the primary material. The volatile products of decomposition may be conducted under the hearth of the furnace and there burnt for heating the crucibles, but it is more advantageous to conduct them into a condensing chamber or into a copper still, and thus recover, after condensation, the tars, oils, essences and hydrocarbons that are produced in the operation.

M. Gaudoin also utilizes these different subproducts in the manufacture of his carbons, and he takes great care to avoid the use of iron, zinc, or any substances susceptible of being attached by these tars to the worms of the receiver, as the whole value rests in purity.

Whatever the primary material employed for the manufacture of this carbon may be, the decomposition by heat should be capable of being conducted either slowly or quickly, according to the nature of the subproducts to be obtained. For operating slowly, it is sufficient to fill the retort two thirds full and heat gradually up to a clear red, avoiding as much as possible the boiling over of the substances. For operating quickly, the empty retort is first heated to a deep red, and the primary material thrown into the bottom in small quantities, in a thin stream, if it is liquid, and in small fragments if it is solid. The slow distillation gives most tars and heavy oils and little gas. The quick decomposition more light oils and gas.

When, then, the primary material has been properly chosen, a carbon, more or less compact, remains in the retort. This is pulverized as finely as possible, and then agglomerated either alone or with a certain quantity of lamp black, by means of the carbides of hydrogen obtained as secondary products. The carbides thus prepared are completely free from iron, and much preferable to those found in commerce, not only for agglomerating the carbon, but also for impregnating or soaking the manufactured objects. The last operation, when effected with commercial products, introduces oxide of iron in the pores. Objects made in agglomerated carbon are, for the same variety of carbon, the more combustible as they are more porous, and more porous as the pressure in moulding is lessened. The inventor uses steel moulds capable of resisting the highest pressure of a strong hydraulic press.

Although the draw plate, or moulding apparatus, that has long been in use for the manufacture of ordinary graphite carbons may also be used in the manufacture of carbons for the electric light, M. Gaudoin has added certain important improvements, that make the apparatus more valuable and better adapted to the work. Thus, instead of causing the carbons to issue from top to bottom, vertically, he places the orifice or orifices of the mould upon the side, and in such a manner that the issuing carbons form, with the horizon, a descending angle of twenty to seventy degrees. The carbon is guided for the whole length by tubes or gutters. This arrangement allows emptying the whole of the matter contained in the mould without interrupting the work; and as the carbon is constantly supported, it does not break under its own weight, which frequently happens when issuing vertically.

We have made, at different times, says M. Fontaine, numerous trials with all kinds of carbons, and those of M. Gaudoin's manufacture have given the best results. It has, however, necessitated much time and considerable expense to remove this manufacture from the merely scientific domain to that of the practical, but success has crowned the efforts of the inventor. The results of some of these experiments, which include the retort, Archereau, Carré and Gaudoin carbons, are given in the accompanying table, No. 1.

No. 1.

TABLE OF EXPERIMENTS MADE NOVEMBER 6, 1876, WITH DIFFERENT KINDS OF CARBONS.

Name of Carbon.	Dimensions.	Consumption.					Regularity.	Observations.
		Speed of Machine.	Of Negative Carbons.	Of Positive Carbons.	Total per Hour.	Mean of Two Experiments.		
		m.m.	m.m.	m.m.	m.m	m. m.		
Retort.	9m. m. square.	800	*19	36	55	63	Irregular.	Scintillating, eclipsed for a short time, a slight disaggregation.
"	9m. m. square.	920	23	48	71		Sufficiently regular.	
Archereau.	10m. m. diam.	800	20	60	80	85	Sufficiently regular.	A slight disaggregation, a few sparks, cinders of oxide of iron in rather large quantities. White light. Cones good.
"	10m. m. diam.	920	30	60	90		Sufficiently regular.	
Carré.	10 4m. m. diam.	800	18	60	78	92	Irregular.	A slight disaggregation, a few sparks, more cinders than the preceding, reddened for a greater length.
"	10 4m. m. diam.	920	26	80	106		Regular enough.	
Gaudoin.	11 3m. m. diam.	800	20	38	58	73	Very regular.	Neither disaggregation nor sparks; less cinders than the Carré and Archereau carbons.
	11 3m. m. diam.	920	38	50	88		Very regular.	

The light produced with the retort carbons was equal to one hundred and three burners, that by the artificial carbons varied between one hundred and twenty and one hundred and eighty burners for the Archereau and Carré carbons, and between two hundred and two hundred and ten for the Gaudoin carbons. The mean of one hundred and fifty burners may be applied, without appreciable error, to the Archereau and Carré carbons, and that of two hundred and five to the Gaudoin carbons.

Reduced to a uniform section of 0.0001 square mètre, the consumption of the carbons was, respectively:

For the retort carbons..............	51 millimètres	(about	2	inches).
" Archereau carbons..........	66 "	"	2.6	"
" Gaudoin "	73 "	"	2.87	"
" Carré "	77 "	"	3	"

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* To convert millimètres into inches, multiply by .03937.

In proportion to the light produced, the consumption was:

For the Gaudoin	carbons,	35	millimètres	(about	1.38	inch)	per	100 burners.
" Archereau	"	44	"	"	1.73	"	"	"
" Carré	"	51	"	"	2	"	"	"
" retort	"	49	"	"	1.93	"	"	"

A Gramme machine, constructed by M. Bréguet, and a Carré lamp by the same maker, were used in conducting these experiments, and the carbons were taken at random from a lot of several mètres for each series.

At the request of one of the inventors, and with the coöperation of Messrs. Gramme and Lemonnier, some additional experiments were made with a more powerful Gramme machine and a Serrin lamp.

No. 2.

RESULTS OF A SERIES OF EXPERIMENTS MADE APRIL 4, 1877, UPON SEVERAL DIFFERENT KINDS OF CARBONS.

Name of Carbon.	Form and Dimensions.	Section in square millimètres.	Total consumption per hour in millimètres.	Mean Light in Cavsel Burners.	Length of the arc in millimètres.	Revolutions per minute of the machine.	Regularity.	Observations.
Retort carbon, good quality.	Square, 9 m. m. in the side.	81	60	120	2.5	820	Passable.	Splinters numerous. Separation of small pieces. Scintillation. Carbons were shaped very irregularly.
Archereau's carbons, new specimen.	Round, 10 m. m. diam.	78	68	173	3	820	Null.	Disaggregation. Sparks. Light very variable in intensity at periods, shaping into small facets.
Carré's carbons, new specimen.	Round, 9 m. m. diam.	64	69	175	3	820	Middling.	Small sparks. Light running round. Very variable in intensity. Good shaping of the carbons.
Gaudoin's, Type No. 1.	Round, 11.2 m. m. diam.	98	80	203	3	820	Good.	Neither sparks nor splinters. Light a little red, but pretty constant.
Gaudoin's Agglomeration of wood carbon.	Round.	—	78	240	3	820	Sufficiently good.	Light very white. Less steady than with Gaudoin's carbons, No. 1. No sparks. Small variations.

The preceding table (No. 2) gives the mean of three series of these experiments, made with the greatest precision. The electric lamp was placed vertically and on the same level with the oil lamp and photometer, and every precaution was taken to prevent any sensible error in the measurements of the luminous intensity.

The rate of consumption of the carbons in these experiments, and reduced to a uniform section of .0001 square mètres, was respectively :

For the Carré carbons	*44	millimètres.
“ retort “	49	“
“ Archereau carbons	53	“
“ Gaudoin (wood carbon)	61	“
“ Gaudoin, No. 1	78	“

In proportion to the light produced, the consumption was as follows :

For the Gaudoin (wood carbon)	32	millimètres	per 100	burners.
“ Archereau carbons	39	“	“	“
“ Carré carbons	40	“	“	“
“ Gaudoin, No. 1, carbons	40	“	“	“
“ retort carbons	50	“	“	“

The light given by the Gaudoin carbons was a little less regular than that observed on November 6, 1876. That given by the Carré carbons varied in less than a minute from one hundred to two hundred and fifty burners; the arc rotated positively round the points, the same as if alternating currents were being used. The Archereau carbons appeared to be less effective than at the first trial; they were consumed slowly, but produced a light so variable that it was difficult to take photometric measurements. Only the retort carbons maintained their durability, luminous intensity, and, unfortunately, also their irregularity.

We cannot do better, while on this subject, than describe the later improvements that M. Gaudoin has made in his process, and which were patented April 7, 1877.

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* To convert millimètres into inches, multiply by .03937.

Instead of carbonizing wood, reducing it to powder, and then submitting it to mixture, the inventor takes dried and properly chosen wood, to which he gives the definite form the carbon is to possess, and then converts it into hard carbon, and finally soaks it in the manner before described.

The distillation of the wood is effected slowly, so as to drive out the volatile substances, and the final desiccation is made in a reducing atmosphere, at a very high temperature. A previous washing, in acids or alkalies, removes from the wood any impurities that it possessed.

M. Gaudoin points out also the means of filling up the pores of the wood, by heating to redness, and submitting it to the action of chloride of carbon and different carbides of hydrogen. He hopes by this means to produce electric carbons of small consumption, and giving an absolutely steady light.

Since the first edition of this work was printed, a series of experiments has been made by a committee of the Franklin Institute, with several of the machines now used for light purposes. Having also been conducted with the greatest care and skill, and including, as they do, accurate measurements of the various factors which affect the general question of electric lighting, these experiments will necessarily possess a great deal of interest for persons whose attention may be directed to the subject, and we, therefore, give a large share of the committee's report in regard to them complete.

Previous to the commencement of the labors of the committee, an invitation was extended to makers of dynamo-electric machines, with a request that they should furnish machines for competitive trial. The machines supplied were two each of the Brush and Wallace-Farmer types, and a Gramme machine which had formed a part of the exhibit of M. Breguet, at the Centennial exhibition.

In measuring the power used, indicator diagrams were taken from the engine, as a check on the dynamometer readings, although the latter were relied upon in making our calculations. except in the case of the large Wallace machine. This machine requiring more power than could be supplied by the institute's engine, or safely transmitted by the dynamometer, it was taken to the works of the I. P. Morris Co., and driven by an engine of 9″ bore and 18″ stroke, and the amount of power consumed determined from the indicator diagrams. This determination was sufficient to demonstrate the fact that this machine possesses no economical advantages over the smaller one of the same make, but the power consumed is omitted from the table of results, as comparisons based on the different methods would be obviously unsatisfactory.

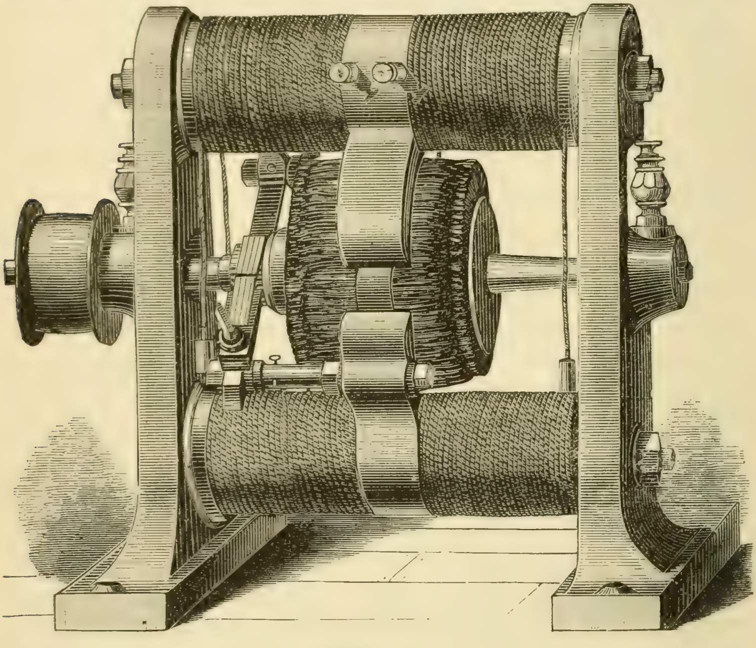

Fig. 16.

The following is a description of the machines submitted to examination. Their dimensions are given in Table III.

The Gramme machine, fig. 16. consists of two cylindrical electro-magnets, with their combined poles extended by pieces of such shape as nearly to envelop the armature which rotates

TABLE III.

SHOWING WEIGHT, POWER ABSORBED, LIGHT PRODUCED, ETC., BY DYNAMO-ELECTRIC MACHINES TESTED BY A COMMITTEE OF THE FRANKLIN INSTITUTE, 1877–8.

NAME OF MACHINE.	Weight in Pounds.	COPPER WIRE IN				Revolutions of Armature per Minute.	Foot Pounds of Power Consumed.	Horse Power.	LIGHT PRODUCED IN STANDARD CANDLES.		Foot Pounds of Power Consumed per Candle Light.	Size of Carbons.	LENGTH OF CARBON CONSUMED PER HOUR.	
		ARMATURE.		FIELD MAGNETS.										
		Size.	Weight.	Size.	Weight.				Total.	Per h. p.			+	−
Large Brush. . .	475	·081 in.	32 lbs.	·134 in.	100 lbs.	1340	107·606	3·26	1230	377	87·4	3/8 × 3/8	1·78	·34
Small Brush. . .	390	·063 in.	24 lbs.	·096 in.	80 lbs.	1400	124·248	3·76	900	239	137·	8/8 × 8/8	1·91	·58
Large Wallace.	600	·042 in.	50 lbs.	·114 in.	125 lbs.	800	. . . .	. . . .	823	. . .	. . . . .	. . . .	. . . .	. . . .
Small Wallace.	350	·043 in.	18¾ lbs.	·098 in.	41 lbs.	1000	128·544	3·89	440	113	292·	¼ × ¼	2·45	·073
Gramme.	366	·059 in.	9½ lbs.	·108 in.	57½ lbs.	800	60.992	1·84	705	383	85·	¼ × ¼	3·15	·55

between them, figs. 17 and 18. The armature is composed of a ring of soft iron, with insulated copper wire wound over its entire surface. This wire is divided into sixty coils, connected successively at their ends, and the loops thus formed between each pair of coils are connected to the copper strips of the commutator. Fig. 18 represents the mode of winding this wire on the ring, only a few turns, however, being shown.

The commutator consists of copper strips equal in number to the armature coils, placed radially edgewise around the shaft of the machine, and insulated from each other and the shaft, thus forming a cylinder, the surface of which is composed of alternate strips of copper and insulating material. Upon the surface of the commutator rest bundles of soft iron wire, by which the currents generated in the armature coils are conducted to the external circuit. As the armature is rotated between the poles of the field magnets, currents of electricity are generated.

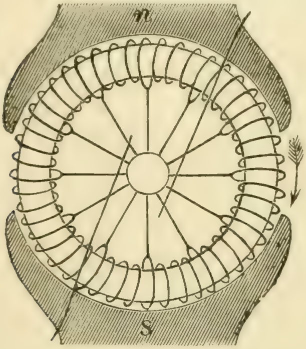

Fig. 17.

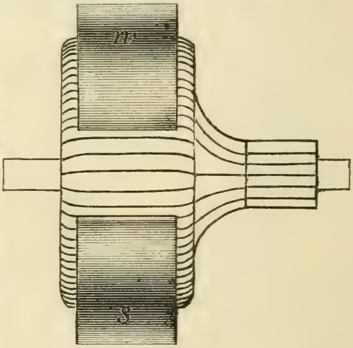

Fig. 18.

These machines are also constructed with two commutators, each connected respectively to alternate armature coils, in which case the external circuit can be divided; but it is usual to pass both currents through the field coils, and then join them in the external circuit. This machine runs smoothly and very quietly, with few or no sparks at the commutator, and very little heating, the temperature of the armature being about 98° Fahr. after running nearly five hours.

The Brush machine, fig. 19, has, for its magnetic field, two horseshoe electro-magnets, with their like poles facing each other, at a suitable distance apart, the circular armature rotating between them.

In this machine the currents are generated in coils of copper wire, wound upon an iron ring, constituting the armature. This ring is not entirely covered by the coils, as in the Gramme armature, but the alternate uncovered spaces between the coils are almost completely filled by iron extensions from the ring, thus exposing large surfaces of the armature ring for the dissipation of heat, due to its constantly changing magnetism, as in the Pacinotti machine.

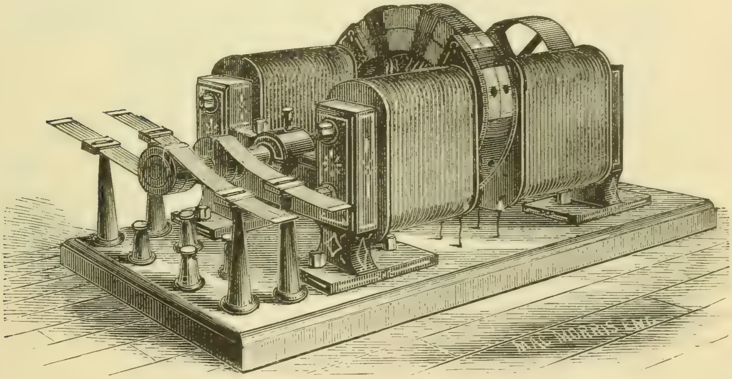

Fig. 19.

The ring revolves between the poles of two large field magnets, the two positive poles of which are at the same extremity of the diameter of the armature, and the two negative poles at the opposite extremity, each pair constituting practically extended poles of opposite character.

The coils on the armature ring are eight in number, opposite ones being connected end to end, and the terminals carried out to the commutator. Figs. 20 and 21 show this arrangement, only one pair of coils, however, being shown in fig. 20 as connected. In order to place the commutator in a convenient position, the terminal wires are carried through the centre of the shaft, to a point outside the bearings.

The commutators are so arranged that, at any instant, three pairs of coils are interposed in the circuit of the machine, working, as it were, in multiple arc, the remaining pair being cut out at the neutral point; while in the Gramme machine, the numerous armature coils being connected end to end throughout, and connections being made to the metal strips composing the commutator, two sets of coils in multiple arc are at one time interposed in the circuit, each set constituting one half of the coils on the armature.

The commutator consists of segments of brass, secured to a ring of non-conducting material, carried on the shaft. These segments are divided into two thicknesses, the inner being permanently secured to the non-conducting material, and the outer ones, which take all the wear, are fastened to the inner in such a manner that they can be easily removed when required.

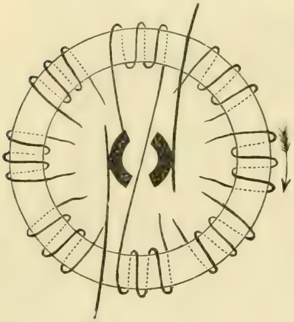

Fig. 20.

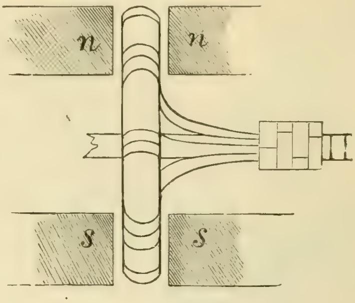

Fig. 21.

The commutator brushes, which are composed of strips of hard brass, joined together at their outer ends, are inexpensive and easily renewed. The high speed at which these machines are run, together with the form of the armature, cause the rotation of the latter to be considerably resisted by the air, and produce a humming sound, but otherwise they run smoothly; the heating of the armature being inconsiderable, not exceeding one hundred and twenty degrees Fahrenheit after four and three quarter hours' run. They are simple in construction, all the working parts being easily accessible, and the cost of maintenance low.

Fig. 19 represents the smaller Brush machine, which is identical in mechanical design with the larger, except that in the former there are two commutators, each of which is connected with alternate armature coils.

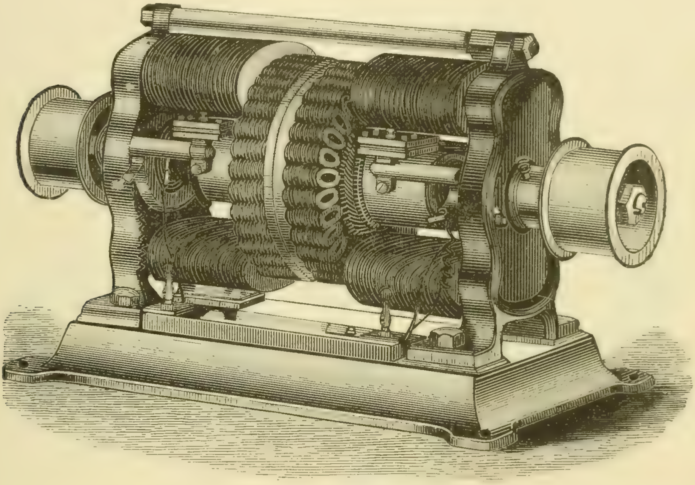

Fig. 22

By this arrangement connections can be so made as to produce electric currents of high or low electromotive force (fifty-five to one hundred and twenty volts, as will hereafter be shown), or the conductor can be divided into two circuits, each of which can be utilized for producing its own light, or for performing other work.

In the Wallace-Farmer machine, fig. 22, the magnetic field is also produced by two horseshoe electro-magnets, but with poles of opposite character facing each other. Between the arms of the magnets, and passing through the uprights supporting them, is the shaft, carrying at its centre the rotating armature.

This consists of a disk of cast iron, near the periphery of which, and at right angles to either face, are iron cores, wound with insulated wire, thus constituting a double series of coils. These armature coils (figs. 23 and 24) being connected end to end, the loops so formed are connected in the same manner, and to a commutator of the same construction, as that of the Gramme. As the armature rotates, the cores pass between the opposed north and south poles of the field magnets, and the current generated depends on the change of polarity of the cores. It will be seen that this constitutes a double machine, each series of coils, with its commutator, being capable of use quite independently of the other; but in practice the electrical connections are so made, that the currents generated in the two series of armature coils pass through the field magnet coils, and are joined in one external circuit. This form of armature also presents considerable uncovered surface of iron to the cooling effect of the air, but its external form, in its fan-like action on the air, like that of the Brush, presents considerable resistance to rotation. In the Wallace-Farmer machine there was considerable heating of the armature, the temperature being sufficiently high to melt sealing wax.

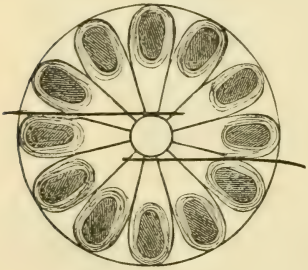

Fig. 23.

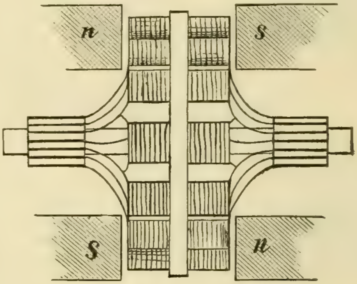

Fig. 24.

The Brush and Wallace-Farmer machines were accompanied by lamps, or carbon holders, which were thought by their makers to present advantages, if not for all machines, at least to be especially adapted to the requirements of their own. The usual Serrin lamp, which is made by M. Breguet for the Gramme machine, did not accompany the latter. The result of experiment, however, quickly established the suitability of the Brush lamp as the source of light for all the machines, and the same lamp, with carbons properly adjusted as to size, was used for the several trials.

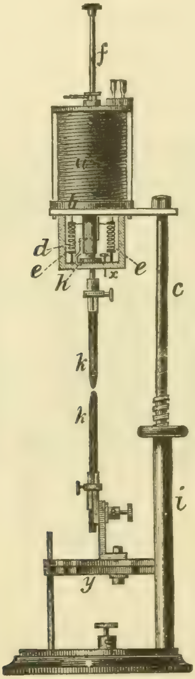

Fig. 25.

This lamp is shown in figs. 25 and 26, in which *a* is a helix of insulated copper wire, resting upon an insulated plate, *b*, upheld by the metallic post *c*. Loosely fitted within the helix is the core *d*, partially supported by the adjustable springs *e*. The rod *f* passes freely through the centre of the core *d*, and has at its lower end a clamp for holding the carbon pencil. A washer, *h*, of brass, surrounds the rod *f*, just below the core *d*, and has one edge resting on the lifting finger attached to the latter, while the other edge is overhung by the head of an adjustable screw stop, *x*.

The metal post *c* is supported and guided by a tubular post, *i*, secured to a suitable base plate. Attached to the lower end of the post *c*, and passing out through a slot in *i*, is the arm *y*, supporting an insulated holder for the lower carbon.

If, now, one conducting wire, from the machine, be connected to the base plate, and the other to the lower carbon holder, the current of electricity will pass up through the posts *i* and *c*, through the helix *a*, rod *f*, and the carbons *k k*, thus completing the circuit.

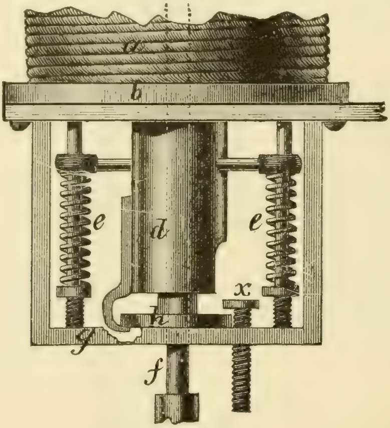

Fig. 26.

The axial magnetism produced in the helix will draw up the core *d*, and it, by means of the lifting finger, will raise one edge of the washer *h*, which, by its angular impingement against the rod *f*, clamps and lifts it to a distance controlled by the adjustable stop *x*, but separating the carbon points far enough to produce the light.

As the carbons burn away, the increased length of the electric arc increases its resistance and weakens the magnetism of the helix, and, therefore, the coil, rod and carbon move downward by the force of gravity, until, by the shortening of the arc, the magnetism of the helix is strengthened and the downward movement arrested. When, however, the downward movement is sufficient to bring the clutch washer *h* to the support *l*, it will be released from the clamping effect of the lifting finger, and the rod *f* will slip through until arrested by the upward movement of the core, due to the increased magnetism of the helix.

The normal position of the clamp washer is with the edge under the adjustable stop, just touching the support *g*, the office of the core being to regulate the slipping of the rod through it. If, however, the rod, from any cause, falls too far, it will instantly and automatically be raised again, as at first, and the carbon points thus continued at the proper distance from each other.

In the lamp used in these experiments, the helix was composed of two separate insulated wires wound together, so that, by means of suitable pin contacts, shown at the top of fig. 25, they could be connected either in couples or end to end, thus varying the intensity of the magnetism of the helix. This, in connection with varying the weight to be lifted by the magnetism of the helix, either by loading the core or increasing the upward thrust of the springs, enabled us to adjust the lamp to suit the varying qualities of the currents dealt with.

In order to make the measurements as accurate as possible, it was found necessary so to arrange the apparatus that no reflected or diffused light should fall on the photometer, and thus introduce an element of error. The arrangement of the apparatus to accomplish this is shown in fig. 27. The electric lamp was enclosed in a box, open at the back for convenience of access, but closed with a non-reflecting and opaque screen during the experiments. Projecting from a hole in the front of the box was a wooden tube, *b*, 6″ square inside and 8′ long, with its inner surface blackened to prevent reflection, thus allowing only a small beam of direct light to leave the box. This beam of light passed into a similar wooden tube, *c*, placed at a proper distance from the first, and holding in its further end the standard candle *d*.

This tube also held the dark box of a Bunsen photometer mounted on a slide, so as to be easily adjusted at the proper distance between the two sources of light. A slit in the side of the tube enabled the observer to see the diaphragm. The outer end of the second tube was also covered with a non-reflecting hood. and the room was, of course, darkened when photometric measurements were taken. The rigid exclusion of all reflected or diffused light is believed to be the only trustworthy method of obtaining true results, and will, no doubt, account in a large measure for the lower candle power obtained by these experiments than that obtained by many previous experimenters.

The difficulties encountered in the measurement of the light, arising from the difference in color, were at first thought to be considerable, but further practice and experience enabled the observer to overcome them to such an extent that the error arising from this cause is inconsiderable, being greatly less than that due to the fluctuations of the electric arc.

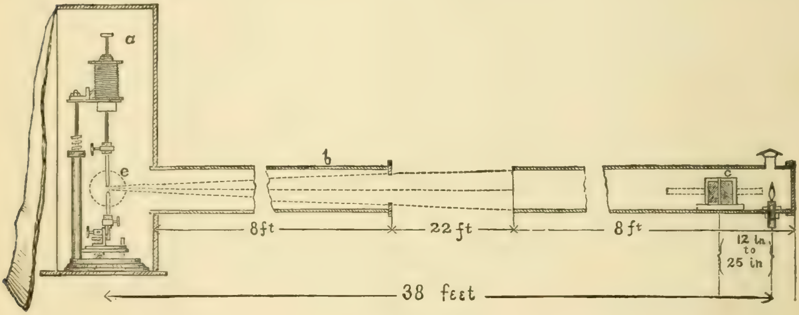

Fig. 27.

The advantage to be derived from using a larger source of light than the standard candle, in measuring the electric light, was considered. A gas flame, giving twenty candles' light, and the oxyhydrogen light, so adjusted as to give seventy to one hundred and thirty-six candles, were carefully measured and used as a comparison. Both of these were found unsatisfactory, and the measurements relied on for our calculations were made entirely with a standard candle, carefully corrected for any variation of consumption from one hundred and twenty grains per hour.

Were much higher intensities of light to be measured, it would be well to use, as a means of comparison, a large gas burner or a multiple wick lamp, such as are employed in lighthouse service, its power being constantly checked by measurements with the standard candle and separate photometer; but, with the volume of light dealt with in these experiments, the candle was sufficiently large, and its direct use greatly reduced the chance of error.

In the earlier experiments, measurements of light, current and power were made simultaneously, thus establishing standard references by which after experiments upon the different points were connected.

In determining the amount of light produced by each machine, it was run continuously for from four to five hours, and observations made at intervals, care being taken to maintain the speed and other conditions normal. One of the most important conditions necessary to insure correct results was the relative position of the carbon points. Great care was taken that the axes of the two sticks or pencils of carbon were in the same line, so that the light produced should be projected equally in all directions. Were the axes of the carbon pencils not in the same line, a much greater quantity of light would be projected in one direction, and the result of calculation of the light produced, based on the inverse square of the distance from the photometer, would be too great or too small, accordingly as this adjustment was in the one or the other direction.

To facilitate observations during the experiments, there was attached at *e*, to the side of the box *a*, holding the electric lamp, a focussing lens, with its axis at right angles to the beam of light, to the photometer, and an image projected upon a screen enabling the observer to see the condition and position of the carbon points without fatiguing the eye. Photographs were also taken, from time to time, at the moment of making the photometric observations—thus securing a permanent record of the condition of the carbon points.

Another difficulty in determining the exact photometric value of the electric light is the fluctuation, or rather, the moving from side to side, of the electric arc, and great care was taken so to adjust the conditions, that the arc or flame should be steady, and equally distributed about the ends of the carbon pencils.

Figs. 28 to 35 are full size, exact reproductions of the photographs taken, and fairly represent the average condition of the carbon when observations were made.

It was found, that although there was a slow consumption of the negative carbon, there was, at the same time, a constant "stalagmatic" growth of particles carried from the positive carbon by the action of the electric current. These stalagmites assumed different forms, as shown in the cuts, but no particular form seemed to be produced by the current from the different machines, except that the deposits on the negative carbon would become greater with increased current. These deposits would build up gradually until they had assumed the forms shown in figs. 33 and 35; then growing narrower near the base, until, by a weakening of the current by this and the consumption of the upper carbon, the lamp would readjust itself, and the piece would drop off. The effect of these growths on the intensity of the light was scarcely appreciable, except for a few seconds before and after the readjustment of the lamp.

Experiments were also made to determine what would be the effect on the amount of light produced by so adjusting the carbons, that the front edge of the upper one was in line with the centre of the lower one. Fig. 36 shows such an adjustment, and is from a photograph taken while measuring the light produced from the small Brush machine, running at twelve hundred and fifty revolutions per minute, and resulting as follows:

Front	2218	candles.
Side	578	"
"	573	"
Back	111	"

3485÷4=871.

The light produced by the same machine, under the same conditions, except the carbons being adjusted in one vertical line, was equal to that of five hundred and twenty-five candles. This would seem to indicate that nearly sixty-six per cent. more light was produced by this adjustment of the carbons; but a close study of the conditions satisfies us that such is not the case, and that there is no advantage to be derived

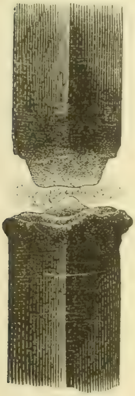
Fig. 28.

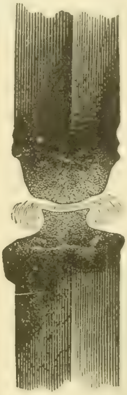
Fig. 29.

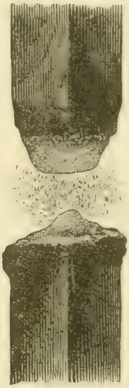
Fig 30.

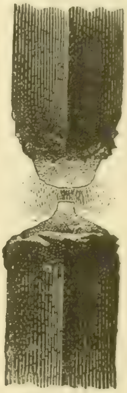
Fig. 31.

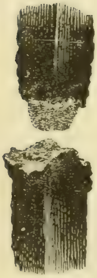
Fig. 32.*

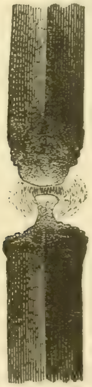
Fig. 33.

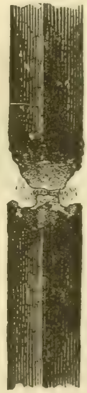
Fig. 34.

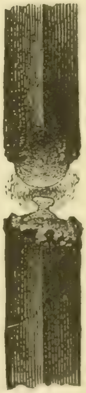
Fig. 35.

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* The voltaic arc should have been shown in fig. 32 as in fig. 34. All the carbons used were coated with copper.

from such adjustment, except when the light is intended to be used in one direction only.

We would here call the attention of those who may compare our results with those obtained at the recent experiments at South Foreland, England, to the following statement upon this point, in the report of Mr. Jas. N. Douglas, engineer to the Trinity House, page sixteen of the official report:

I have found this arrangement of the carbons (the axis of the bottom carbon nearly in the same vertical plane as the front of the top carbon), and assuming the intensity of the light with the carbons having their axis in the same vertical line to be represented by one hundred, the intensity of the light in four directions in azimuth, say east, west, north and south, will be nearly as follows:

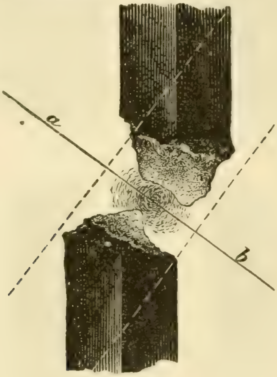


Fig 36.

East or front intensity	287 to 100
North or side	116 to 100
South or "	116 to 100
West or back	38 to 100
	557÷4=139 to 100

* * * * * * *

In measuring the candle power of the light produced by each machine, I have given the mean intensity obtained in the direction of the photometer, the carbons in lamp working with the Holmes and Alliance machines being always arranged with the axes in the same vertical line, and the carbons in the lamp working the Gramme and Siemens machine being always arranged with the front edge of the top carbon nearly on the centre of the bottom carbon.

It is, therefore, evident that the results given by Mr. Douglas must be divided by 2·87 in making a comparison with those obtained by us.

Thus, in the table on page 31 of the official report, in the column headed light produced by horse power in standard candles, he gives for the Gramme machine condensed beam twelve hundred and fifty-seven; but if this be divided by 2·87, we have four hundred and thirty-eight candles, which is, no doubt, still too high, our result of three hundred and eighty-three candles per horse power for the Gramme being obtained under the careful and rigid conditions before named.

In many battery circuits a high external resistance may be employed, and the electromotive force remain comparatively constant, while in dynamo-electric machines, in which the reaction principle is employed, the introduction of a very high external resistance into the circuit must be necessarily attended by decided variations in the electromotive force, due to changes in the intensity of the magnetic field in which the currents have their origin. Moreover, a considerable difficulty is experienced in the great variations in the behavior of these machines when the resistance of the arc, or that of the external work, is changed. Changes, due to loss of conductivity by heating, also take place in the machine itself.

The variations above mentioned are also attended by changes in the power required to drive the machine, and in the speed of running, which again react on the current generated.

There are certain normal conditions in the running of dynamo-electric machines designed for light, under which all measurements must be made, viz.:

1. The circuit must be closed, since, on opening, all electrical manifestations cease.

2. The circuit must be closed through an external resistance equal to that of the arc of the machine.

3. The arc taken as the standard must be the normal arc of the machine. This condition can only be fulfilled by noticing the behavior of the machine while running, as to the absence of sparks at the commutator, the heating of the machine, the regularity of action in the consumption of carbons in the lamp, etc.

4. The speed of the machine must be, as nearly as possible, constant.

5. The power required to maintain a given rate of speed must be, as nearly as possible, constant.

The machines submitted to us for determinations were, as already stated:

1. Two machines of different size, and of somewhat different detailed construction, built according to the invention of Mr. C. F. Brush, and styled respectively in our report as A^1, the larger of the two machines, and A^2, the smaller.

2. Two machines known as the Wallace-Farmer machines, differing in size, and in minor details of construction, and designated respectively as B^1, the larger of the two, and B^2, the smaller. In the case of the machine B^1, the experiments were discontinued after the measurement of the resistances was made, insufficient power being at our disposal to maintain the machine at its proper rate of speed.

3. A Gramme machine of the ordinary construction.

All the above machines are constructed so that the whole current traverses the coils of the field magnets, being single current machines, in which the reaction principle is employed. In the case of the machine designated A^2, the commutators are so arranged as to permit the use of two separate circuits when desired.

For the purpose of preserving a ready measure of the current produced by each machine, under normal conditions, a shunt was constructed by which an inconsiderable but definite proportion of the current was caused to traverse the coils of a galvanometer, thus giving with each machine a convenient deflection, which could at any time be reproduced. As the interposition of this shunt in the circuit did not appreciably increase its resistance, the normal conditions of running were preserved.

As indicating the preservation of normal conditions in any case, the speed of running and the resistances being the same as in any previous run, it was found that when there was an equal expenditure of power, as indicated by the dynamometer, the current produced, as indicated by the galvanometer, was in each case the same.

Certain of the machines experimented with heated considerably on a prolonged run; most of the tests, therefore, were made when the machines were as nearly as possible at about the temperature of the surrounding air. It is evident that no other standard could be well adopted, as under a prolonged run the temperature of the different parts of the machine would increase very unequally; and, moreover, it would be impossible to make any reliable measurements of the temperatures of many such parts.

In measuring the resistance of the machines, a Wheatstone's bridge, with a sliding contact, was used in connection with a delicate galvanometer and a suitable voltaic battery. In taking the resistances of the machines, several measurements were made with the armatures in different positions, and the mean of these measurements taken as the true resistance.

It was, of course, a matter of the greatest importance to obtain a value for the resistance of the arc in any case, since upon the relative values of this resistance, and that of the machine, the efficiency would in any given case, to a great extent, depend. In each case, the arc of which the resistance was to be taken was that which was obtained when each machine was giving its average results as to steadiness of light and constancy of the galvanometer deflection.

The method adopted for the measurement of the arc was that of substitution, in which a resistance of german silver wire immersed in water was substituted for the arc, without altering any of the conditions of running. This substituted resistance was afterwards measured in the usual way, and gave, of course, the resistance of the arc. It could, therefore, when so desired, serve as a substitute for the arc. No other method of obtaining the arc resistance appeared applicable, since the constancy of the resistance of the arc required the passage of the entire current through the carbons.

It may be mentioned, as an interesting fact in this connection, that when the current flowing was great, the arc corresponding thereto had a much lower resistance than when the current was small. This fact is, of course, due to increased vaporization, consequent on increased temperature in the arc.

In determining the true arc resistance, the resistance of the electric lamp controlling the arc was measured separately, and deducted from the result obtained with the german silver wire substitute.

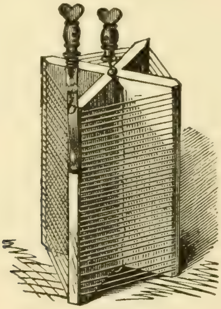


Fig. 37.

For ease of obtaining a resistance of german silver wire equal in any case to that of the arc, a simple rheostat was constructed, by winding, upon an open frame, such a length of wire as was judged to be in excess of the resistances of any of the arcs to be measured. By means of a sliding contact, successive lengths of the wire were added, until the conditions as above stated were reproduced. Fig. 37 shows the arrangement of the rheostat. With this arrangement, no difficulty was experienced in reproducing the same conditions of normal running as when the arc was used. The same conducting wires were used throughout these experiments. Being of heavy copper, their resistance was low, viz.: about ·016 ohm.

Having thus obtained the circuit resistances, we proceeded to determine the value of the current. Here the choice of a number of methods presented itself. We selected two methods, one based on the production of heat in a circuit of known resistance, and the other upon the comparison of a definite proportion of the current with that of a Daniell's battery.

In the application of the first method, eight litres of water, at a known temperature, were taken and placed in a suitable non-conducting vessel. In this was immersed the german silver wire before mentioned, and the sliding contact so adjusted as to afford a resistance equal to that of the normal arc of the machine under consideration. This was now introduced into the circuit of the machine. All these arrangements having been made, the temperature of the water was accurately obtained, by a delicate thermometer, reading readily to quarter degrees Fahrenheit. The current from the machine running under normal conditions was allowed to pass, for a definite time, through the calorimeter so provided. From the data thus obtained, after making the necessary corrections as to the weight of the water employed, the total heating effect in the arc and lamp, as given in Table IV., was deduced.

Since the heat in various portions of an electrical circuit is directly proportional to the resistance of those portions, the total heat of the circuit was easily calculated, and is given in Table V., in English heat units. For ease of reference, the constant has been given for conversion of these units into the now commonly accepted units of heat.

Having thus obtained the heating effect, the electrical current is readily determined by the well known formula,

$$C = \sqrt{\frac{W h \times 772}{R t c}},$$

where $C =$ the veber current per ohm, W the weight of water in

TABLE IV.—RESISTANCES OF DYNAMO-ELECTRIC MACHINES.

From determinations by EDWIN J. HOUSTON and ELIHU THOMSON.

NAME OF MACHINE.	Temperature in Degrees F.	RESISTANCES		Resistance of Conducting Wire.	Resistance of Lamp, Exclusive of Arc.	CORRECTED RESISTANCES		Total Resistance of the Circuit. Ohms.	REMARKS.
		Of Machine +Conductor.	Of Arc +Lamp.			Of Machine —Conductor.	Of Arc —Lamp.		
A^1, large Brush....	73½	·485	·57	·016	·032	·483	·54	1·055	At beginning of run.
A^1, " "	88	·495	·82	·016	·032	·493	·79	1·315	After running 25 min.
A^2, small Brush....	74	1·255	1·70	·016	·032	1·239	1·67	2·955	Arranged for low resist.
A^2, " "	74	5·06	....	·016	.....	5·044	....	.....	" " high "
B^1, large Wallace...	74	4·60	1·98	·016	·032	4·584	1·95	6·58	Machine cold.
B^1, " " ..	118	5·13	....	·016	....	.....	....	....	After 40 min. run.
B^2, small Wallace...	74	4·96	2·87	·016	·1025	4·944	2·77	7·83	At 844 rev.
B^2, " " ..	74	4·96	3·24	·016	·1025	4·941	3·18	8·24	" 1000 rev.
Gramme...........	68	1·685	1·35	·016	·1025	1·669	1·25	3·04	Arc not normal.
"	68	1·685	1·97	·016	·1025	1·669	1·87	3·66	Arc normal.

TABLE V.—THERMIC EFFECTS OF DYNAMO-ELECTRIC MACHINES.

From determinations by EDWIN J. HOUSTON and ELIHU THOMSON.

NAME OF MACHINE.	Galvanometer Deflection with Shunt.	HEATING EFFECT IN ARC AND LAMP.			Resistance of Calorimeter equal to arc.	Heat in arc and lamp, in pounds H_2O, 1° F.	Total heat of the circuit, in pounds H_2O, 1° F.	Heat per ohm, per second.	Speed of machine. Rev. per minute.	Dynamometer reading, including Friction.
		Lbs. H_2O.	Increase degrees Fahr.	Duration of run.						
A^1, large Brush.......	51½°	18·64	23·35	10	8·2	43·338	69·49	·881	1340	107606
A^2, small Brush.......	34	18·63	9·09	5	1·70	33·87	58·87	·332	1200	117700
A^2, " "	37	18·63	18·66	8	1·70	43·45	75·57	·426	1400	124248
B^2, small Wallace.....	25½	18·63	11.50	12	2·87	17·85	48·70	·104	844	97068
B^2, " "	25½	18.63	4·92	6	2·87	15·28	41·69	·089	844	97068
B^2, " "	24½	18·64	10·75	10	3·28	20·04	50·34	·102	1040	128544
Gramme.............	38	18·64	16·25	10	1·97	30·29	56·28	·256	800	60992

For conversion to new heat units—1 lb. water, 1° F., = 259·185 grammes of water, 1° C.

pounds, *h* the increase of temperature in degrees Fahrenheit, seven hundred and seventy-two Joule's constant, *R* the resistance in ohms, *t* the time in seconds, and *c* the constant, ·737335 the equivalent in foot pounds of one veber per ohm per second. The currents so deduced for the different machines are given in Table VI.

The other method employed for obtaining the current, viz., the comparison of a definite portion thereof, with the current from a Daniell's battery, was as follows: a shunt was constructed, of which one division of the circuit was ·12 ohm, and the other three thousand ohms. In this latter division of the circuit was placed a low resistance galvanometer, on which convenient deflections were obtained. This shunt being placed in the circuit of the machine, the galvanometer deflections were carefully noted. To the resistance afforded by the shunt, such additional resistance was added as to make the whole equal to that of the normal arc of the machine. These substituted resistances were immersed in water, in order to maintain an equable temperature.

Three Daniell's cells were carefully set up and put in circuit with the same galvanometer used above, and with a set of standard resistance coils. Resistances were unplugged sufficient to produce the same deflections as those noted with the shunt above mentioned. The shunt ratio, as nearly as could conveniently be obtained, was $\frac{1}{25000}$. Then the formula,

$$C = \frac{s\,n \times 1{\cdot}079}{R},$$

where *C* equals the veber current, *s* the reciprocal of the shunt ratio, *n* the number of cells employed, 1·079 the assumed normal value of the electro-motive force of a Daniell's cell, and *R* the resistances in the circuit with the battery, gives at once the current. In comparison with the total resistances of the circuit, the internal resistance of the battery was so small as to be neglected.

The results obtained were as follows:

Name of Machine.	Shunt Ratio.	Number of Daniell's Cells.	Resistances Unplugged.	Speed of Machine.
Large Brush.........	$\frac{1}{25000}$	3	2710 ohms.	1340 rev.
Small Brush.........	$\frac{1}{25000}$	3	3700 "	1400 "
Wallace-Farmer	$\frac{1}{25000}$	3	8320 "	844 "
....	$\frac{1}{25000}$	3	6980 "	1040 "
Gramme.............	$\frac{1}{25000}$	3	4800 "	800 "

The veber currents, as calculated from the above data, are given in Table VI.

From the results thus derived, the electro-motive force was deduced by the general formula,

$$E = C \times R.$$

The electro-motive force thus calculated will be found in Table VI.

Statements are frequently made, when speaking of certain dynamo-electric machines, that they are equal to a given number of Daniell's, or other well known battery cells. It is evident, however, that no such comparison can properly be made, since the electro-motive force of a dynamo-electric machine, in which the reaction principle is employed, changes considerably with any change in the relative resistances of the circuit of which it forms a part, while that of any good form of battery, disregarding polarization, remains approximately constant. The internal resistance of dynamo-electric machines is, as a rule, very much lower than that of any ordinary series of battery cells, as generally constructed; and, therefore, to obtain with a battery, conditions equivalent to those in a dynamo-electric machine, a sufficient number of cells in series would have to be employed to give the same electro-motive force; while, at the same time, the size of the cells, or their number in multiple arc, would require to be such that the internal resistance should equal that of the machine.

Suppose, for example, that it be desired to replace the large Brush machine by a battery whose electro-motive force and internal and external resistances are all equal to that of the

TABLE VI.—CURRENT AND ELECTRO-MOTIVE FORCE OF DYNAMO-ELECTRIC MACHINES.

From determinations by EDWIN J. HOUSTON and ELIHU THOMSON.

NAME OF MACHINE.	VEBER CURRENT PER OHM PER SECOND.		ELECTRO-MOTIVE FORCE IN VOLTS.		Per cent. of the work of current appearing in the arc.	Corresponding Dynamometric Values.	REMARKS.
	From heat developed.	By comparison with Daniell's batt.	Calc. from heat and resistance.	By comparison with Daniell's batt.			
A^1, large Brush......	30·37	29·87	39·94	39·28	60·08	107606	Speed 1340 rev.
A^2, small Brush......	18.63	.....	55·05	.....	.....	117700	" 1200 "
A^2, " "	21·12	21·87	62·41	64·63	56·51	124248	" 1400 "
B^2, small Wallace....	10·42	9·73	81·59	76·19	35·38	97068	" 844 "
B^2, " "	9·64	.....	75·48	.....	.....	......	" 844 "
B^2, " "	10·33	11·16	85·12	91·96	38·59	128544	" 1040 "
Gramme............	16·38	16·86	59·95	61·71	51·09	60992	" 800 "

machine, and that we adopt as a standard a Daniell's cell, of an internal resistance of, say, one ohm. Referring to Table VI., the electro-motive force of this machine is about thirty-nine volts, to produce which about thirty-seven cells, in series, would be required; but, by Table IV., the internal resistance of this machine is about ·49 ohm. To reduce the resistance of our standard cell to this figure, when thirty-seven cells are employed in series, seventy-six cells, in multiple arc, would be required. Therefore, the total number of cells necessary to replace this machine would equal thirty-seven by seventy-six, or two thousand eight hundred and twelve cells, working over the same external resistance. It must be borne in mind, however, that although the machine above mentioned is equal to two thousand eight hundred and twelve of the cells taken, that no other arrangement of these cells than that mentioned, viz., seventy-six in multiple arc, and thirty-seven in series, could reproduce the same conditions, and, moreover, the external resistances must be the same. The same principles, applied to the other machines, would, when the internal resistance was great, require a large number of cells, but arranged in such a way as to be extremely wasteful, from by far the greater portion of the work being done in overcoming the resistance of the battery itself.

The true comparative measure of the efficiency of dynamo-electric machines as means for converting motive power into work derived from electrical currents, whether as light, heat or chemical decomposition, is found by comparing the units of work consumed with the equivalent units of work appearing in the circuit external to the machine. In Table VII., the comparative data are given. In the first column the dynamometer reading gives the total power consumed; from which are to be deducted the figures given in the second column, being the work expended in friction, and in overcoming the resistance of the air; although, of course, it must be borne in mind, that that machine is the most economical in which, other things being equal, the resistance of the air and the friction are the least. The third column gives the total power expended in producing electrical effects, a portion only of which, however, appears in the effective circuit, the remainder being variously consumed in the production of local circuits in the different masses of metal composing the machines. This work eventually appears as heat in the machine. Columns four, five and six give respectively the relative amounts of power variously appearing as heat in the arc, in the entire circuit, and as heat due to local circuits in the conducting masses of metal in the machine, irrespective of the wire. This latter consumption of force may be conveniently described as due to the *local action* of the machine, and is manifestly comparable to the well known local action of the voltaic battery, since in each case it not only acts to diminish the effective current produced, but also adds to the cost.

We desire to call attention to the fact, that in all the determinations conducted by us, we have been particularly careful to insure a definite relation between the external and internal resistances in each case—a condition of paramount importance in the effective working of these machines. It is evident, indeed, that no determinations made with an unknown or abnormal external resistance can be of any value, since the proportion of work done, in the several portions of an electrical circuit, depends upon, and varies with, the resistances they offer to its passage. If, therefore, in separate determinations with any particular machine, the resistance of that part of a circuit of which the work is measured be, in one instance large, in proportion to that of the remainder of the circuit, and in another small, the two measurements thus made would give widely different results, since in the case where a large resistance was interposed in this part of the circuit, the percentage of the total work appearing there would be greater than if the small resistance had been used.

When an attempt has been made to determine the efficiency of a single machine, or of the relative efficiency of a number of machines, by noting the quantity of gas evolved in a voltameter, or by the electrolysis of copper sulphate in a decomposing cell, when the resistance of the voltameter or decomposing cell did not represent the normal working resistance, it is manifest that the results cannot properly be taken as a measure of the actual efficiency.

In Table IV. it will be found, that in general, where the machine used had a high internal resistance, the arc resistance normal to it was also high, but they are not necessarily dependent upon each other. The arc resistance depends on the intensity of the current, the nature of the carbons, and on their distance apart. Other conditions being the same, the resistance of the arc is less when the current is great.

Since all the machines examined were built for lighting, it will readily be seen that, other things being equal, that machine is the most economical in which the work done in the arc bears a considerable proportion to that done in the whole circuit, and since, with any given current, the work is proportional to the resistance, we have in Table IV. the data for comparison in this regard. For example, in the second determination of A^1, the large Brush machine, the resistance of the arc constitutes considerably more than one half the total resistance of the entire circuit, while in B^2, the small Wallace-Farmer machine, it constitutes somewhat more than one third the total resistance. These relative resistances give, of course, only the proportion of the current generated, which is utilized in the arc as light and heat, the conditions of power consumed to produce the current not being there expressed.

During any continued run, the heating of the wire of the machine, either directly by the current, or indirectly from conduction from those parts of the machine heated by local action, as explained in a former part of this report, produces an increased resistance, and a consequent falling off in the effective current. Thus, in Table IV., at the temperature of 73·5° Fahr., A^1, the large Brush machine, had a resistance of ·485 ohm, while at eighty-eight degrees Fahrenheit, at the armature coils, it was ·495 ohm. These differences were still more marked in the case of B^1.

In A^2, the small Brush machine, it will be noticed that two separate values are given for the resistance of the machine.

These correspond to different connections, viz., the resistance, 1·239 ohms, being the connection at the commutator for low resistance, the double conducting wires being coupled in multiple arc, while 5·044 ohms represent the resistance when the sections of the double conductor are coupled at the commutator in series.

Referring to Table V., the numbers given in the column headed "Heat in arc and lamp," are the measure of the total heating power in that portion of the circuit external to the machine. They do not, however, in the case of any machine, represent the energy which is available for the production of light, which depends also on the nature and the amount of the resistance over which it is expended. For example, the heat in arc and lamp are practically the same in each of the Brush machines, if the measurement of the smaller of these machines be taken at the higher speed. The amount of light produced, however, is not the same in these two instances, being considerably greater in the case of the larger machine. The explanation of this apparent anomaly is undoubtedly to be found in the different resistances of the arcs in the two cases. In the large Brush machine the carbons are nearer together than when the small machine is used. This suggests the very plausible explanation, that the cause of the difference is to be attributed to the fact, that, although the total heating effect is equal in each case, when the large machine is used, the heat produced is evolved in a smaller space, and its temperature, and consequent light giving power, thereby largely increased.

It would seem, indeed, that any future improvements made in the direction of obtaining an increased intensity of light from a given current, will be by concentrating the resistance normal to the arc in the most limited space practicable, thereby increasing the intensity of the heat, and, consequently, its attendant light.

It may be noted, in this connection, that in all the cases in which the resistance of the arc was low, the photometric intensity was high. This, indeed, might naturally be expected, since a great intensity of heat would, under existing conditions of the use of the arc, admit of increased vaporization, and consequent lowering of the resistance.

In the column headed "Total heat of circuit," are given the quantities of heat developed in the whole circuit, which numbers, compared with those in the preceding column, furnish us with the relative proportions of the work of the circuit, which appear in the arc and lamp.

The column headed "Heat per ohm per second," gives the relative work per ohm of resistance in each case, and these numbers, multiplied by the total resistance, give the total energy of the current expressed in heat units per second.

In Table VI. are given the results of calculation and measurement, as to the electric work of each machine. It is evident, to those acquainted with the principles of electrical science, that in the veber current and the electro-motive force, we have the data for comparing the work of these machines with that of any other machine or battery, whether used for light, heat, electrolysis, or any other form of electrical work.

As might be supposed, the values given in Table VI., of the veber current, approximate relatively to the photometric values, as will be seen from an examination of that part of the general report of the committee relating to photometric measurements.

The values of the veber current, as deduced from the heat developed, and from the comparison with a Daniell's cell, do not exactly agree; nor could this have been expected, when the difficulty of minutely reproducing the conditions as to speed, resistance, etc., is considered.

By comparison of the electro-motive force of the different machines, it appears that no definite unit seems to have been aimed at by all the makers as that best adapted to the production of light.

Table VII. is designed especially to permit a legitimate comparison of the relative efficiency of the machines, as well as their actual efficiency in converting motive power into current. The actual dynamometer reading for which we are indebted to the subcommittee on the measurements of power, is given in the first column. On account of differences of construction, and differences in speed of running, the friction and resistance of the

TABLE VII.—EFFECTS OF DYNAMO-ELECTRIC MACHINES IN FOOT POUNDS PER MINUTE.

From determinations by EDWIN J. HOUSTON and ELIHU THOMSON.

NAME OF MACHINE.	Dynamometer reading. F. P. consumed.	Friction and resistance of air.	F. P. consumed, after deducting friction.	F. P. appearing in arc as heat.	F. P. appearing in whole circuit.	F. P. unaccounted for in the circuit.	Per cent of power utilized in arc.	Per cent. of effect after deducting friction.
A ^{1}, large Brush......	107606	17950	89656	33457	53646	36010	31	37½
A ^{2}, small Brush.......	117700	12328	105372	26148	45448	59924	22	25
A ^{2}, " "	124248	14976	109272	33543	58340	50932	27	31
B ^{2}, small Wallace.....	99068	7800	89268	13780	37596	51672	14	15½
B ^{2}, " "	128544	11072	117472	15469	38862	78610	12	13
Gramme.............	60992	4512	56480	23384	43448	13032	38	41

For conversion into Gramme metres — 1 foot pound = 138 Gramme metres, nearly.

air vary greatly, being least with the Gramme, as might be expected, since the form of the revolving armature, and the speed of the machine, conduce to this result. This is, of course, a point greatly in favor of the Gramme machine.

That portion of the power expended available for producing current is given in the third column, being the remainder, after deducting the friction, as before mentioned; but this power is not in any case fully utilized in the normal circuit. This is found to be the case by comparing calculations of the total work of the circuit in foot pounds, as given in the appropriate column, with the amount expended in producing such current.

For instance, in the case of A^1, the large Brush machine, the available force for producing current is 89656 f. p. per minute, of which only 53646 reappear as heat in the circuit. The balance is most probably expended in what we have termed *local action*, that is, the production of local currents in the various conducting masses of metal composing the machine. The amount thus expended in local action is given in the column designated "F. p. unaccounted for in the circuit." A comparison of the figures in this column is decidedly in favor of the Gramme machine, it requiring the smallest proportion of power expended, to be lost in local action. When, however, we consider that the current produced by the large Brush machine is nearly double that produced by the Gramme, the disproportion in the local action is not so great. The columns containing the percentages of "Power utilized in the arc," and "Useful effects after deducting friction," need no special comment.

The determination which we have made, as described in the foregoing part of this report, have enabled us to form the following opinions as to the comparative merits of the machines submitted to us for examination:

1. The Gramme machine is the most economical, considered as a means for converting motive power into electrical current, giving in the arc a useful result equal to thirty-eight per cent., or to forty-one per cent. after deducting friction and the resistance of the air. In this machine the loss of power in friction

and local action is the least, the speed being comparatively low. If the resistance of the arc is kept normal, very little heating of the machine results, and there is an almost entire absence of sparks at the commutator.

2. The large Brush machine comes next in order of efficiency, giving in the arc a useful effect equal to thirty-one per cent. of the total power used, or thirty-seven and one half per cent. after deducting friction. This machine is, indeed, but little inferior in this respect to the Gramme, having, however, the disadvantages of high speed and a greater proportionate loss of power in friction, etc. This loss is nearly compensated by the advantage this machine possesses over the others, of working with a high external, compared with the internal resistance, thus also insuring comparative absence of heating in the machine. This machine gave the most powerful current, and consequently the greatest light.

3. The small Brush machine stands third in efficiency, giving in the arc a useful result equal to twenty-seven per cent., or thirty-one per cent. after deducting friction. Although somewhat inferior to the Gramme, it is, nevertheless, a machine admirably adapted to the production of intense currents, and has the advantage of being made to furnish currents of widely varying electro-motive force. By suitably connecting the machine, as before described, the electro-motive force may be increased to over one hundred and twenty volts. It possesses, moreover, the advantage of division of the conductor into two circuits, a feature which, however, is also possessed by some forms of other machines. The simplicity and ease of repair of the commutator are also advantages. Again, this machine does not heat greatly.

4. The Wallace-Farmer machine does not return to the effective circuit as large a proportion of power as the other machines, although it uses, in electrical work, a large amount of power in a small space. The cause of its small economy is the expenditure of a large proportion of the power in the production of local action. By remedying this defect, a very admirable machine would be produced.

Within a short time past a new dynamo machine, invented by Mr. Hiram Maxim, of this city, has been brought out, and is now being introduced by the United States Electric Lighting Company. This machine requires one and a half horse power to drive it. It weighs three hundred pounds, and produces a light of from 1,200 to 2,000 sperm candles, according to speed. The magnets are similar in form to those used by Dr. Siemens, of London, but the armature, or revolving portion, is a new design, which is said to be free from many objections common to other machines. The only point where any considerable wear takes place on these machines is in the commutator, in which a stationary copper brush takes the current from the revolving part.

In some machines this portion has been built into the machine, so that when it is worn the whole machine would require rebuilding in case of repair. Mr. Maxim has constructed his machine so that the removal of a nut loosens the parts subject to wear, so that they may be replaced in a few minutes, and at a trifling cost.

Mr. Maxim has also produced a new lamp, which is shown in the accompanying figures. Fig. 38 represents a vertical section, fig. 39, a perspective view of the same, and fig. 40, a detail. A is the positive carbon holder and B the negative. The operation of this lamp is as follows:

The negative carbon, which may be six inches long, being secured in the lower holder B, the top holder may be drawn up, as the pinion that gears into its rack is free to turn in that direction without driving the train of gears. A carbon eleven inches long may now be inserted in the top holder, and its point brought in line with the lower carbon by moving the lever on the back of the carrier.

The wires being connected to the binding post (one on each side of the lamp), the thumb nut G, being turned, will allow the weight of the positive carrier to rotate the train of gearing, and by winding up a cord, to draw the negative upward until the combined movement of both causes the points of the two carbons to meet. This will establish an electrical contact, the

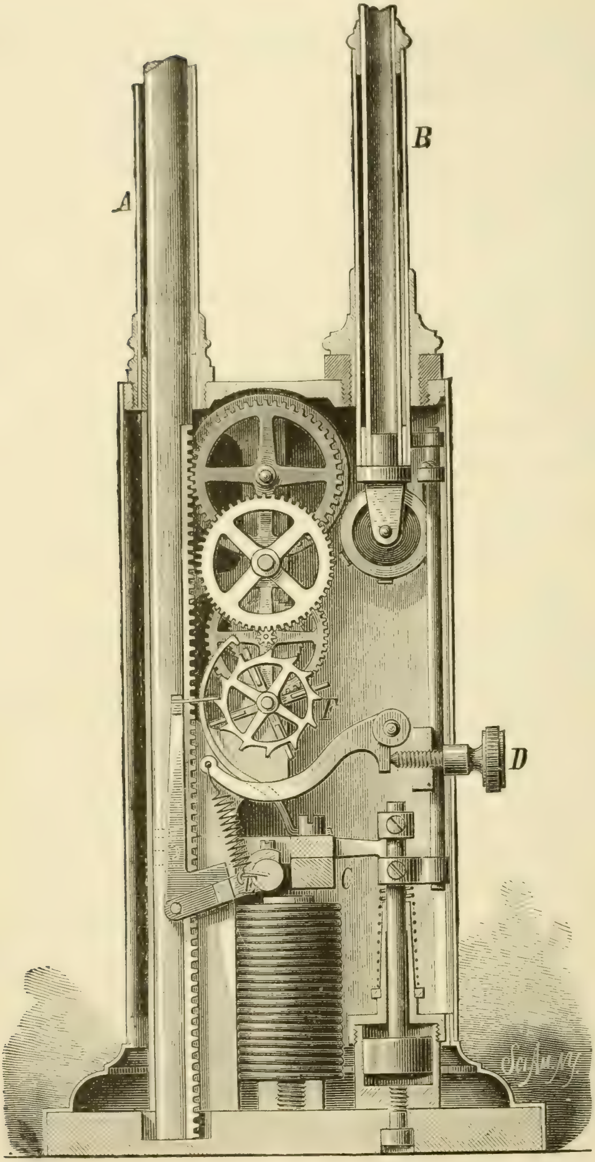
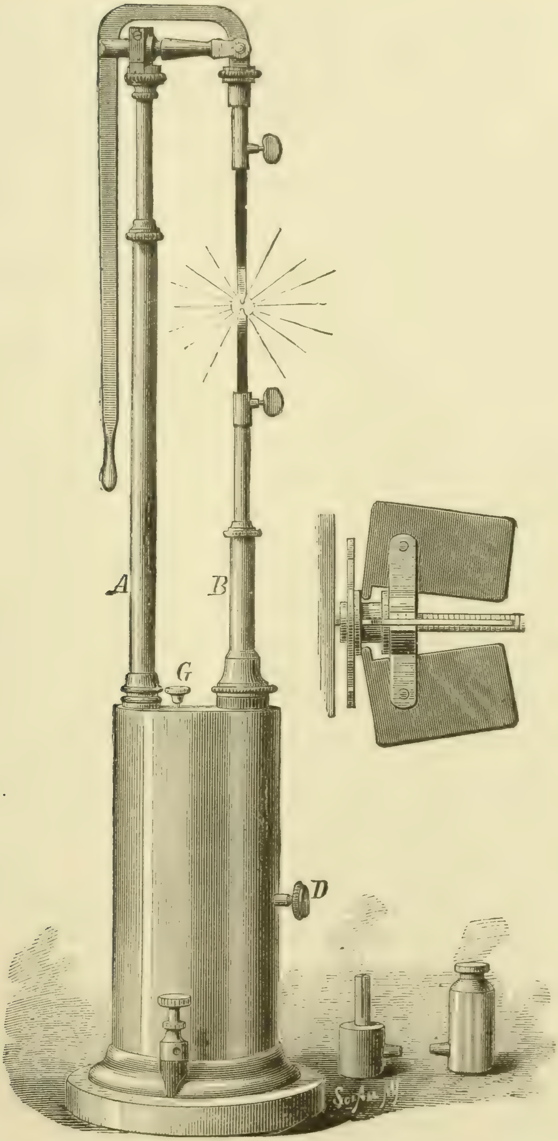


Fig. 38.



Figs. 39 *and* 40.

current will at once commence to pass, and the electro magnet in the bottom of the lamp will become excited and draw downward the two armatures, one of which draws down one end of the cord that supports the negative carbon, and the other locks the gearing. The separation of the carbons by this downward movement of the negative establishes the voltaic arc, when the light comes out in all its splendor. As the carbons waste away the arc becomes longer, and the resistance to the passing current becomes greater, its power to excite the electro magnet correspondingly decreasing. The armature E is drawn away from the magnet by a retractile spring, the tension of which is adjusted by thumb screw D. When the magnetism is so much reduced that the pull of the spring is greater than the pull of the magnet, the spring will force the armatures upward and remove the detent from the ratchet wheel F, thus allowing the train of gears to move so that the carbons slowly approach each other, until a point is reached where the arc is shortened sufficiently to again bring the magnet up to its original strength, when it will again pull down the armature and lock the gearing. A too rapid movement of the parts is prevented by a small fan, shown in fig. 40. When the carbons are drawn apart to a considerable distance and then allowed to approach, this fan will revolve with great speed, and its wings will be spread by centrifugal action to their fullest extent; but when the carbons touch, and the electrical current is established, its speed is much reduced, as the larger armature C is drawn down, and it remains in that position while the circuit is complete. The armature has an attachment which is brought within the field of the extended wings, but it cannot reach them when they are closed. The fan, when engaged by the attachment, can revolve only a quarter turn at a time and at a very slow speed.

When the ratchet F, on the fan shaft, is unlocked, it can revolve rapidly only when the current is broken, and when it is released to feed the carbons to an already established arc, it can only turn at a speed a little faster than the actual consumption of the carbons. Should the arc be broken, or the light be extinguished, from a high wind or other cause, the large armature C will be liberated, and by bringing the lower carbon against the upper carbon, it reëstablishes the arc instantly. A too rapid movement is prevented by a controlling chamber or dash pot in the bottom of the lamp. All the comparatively heavy work of separating the carbons and reëstablishing the current is done by the armature C, while the smaller armature E has only to lock and unlock the train of gearing.

As the distance to be travelled is very slight, and the work to be done so light, but very little change in the electro-motive force of the current is required to stop or start the feeding of the carbons. The tension of the spring that opposes the magnetism can be adjusted from the outside of the case to balance its pressure against a current of any strength. Where great nicety and steadiness are required, this lamp seems well adapted to meet all requirements. It is small and compact, and appears a very substantial and beautiful piece of mechanism.

Fig. 41 is a side elevation of a less expensive kind of lamp, devised by the same inventor. In this lamp both carbon holders are supported by a cord. As the upper or positive holder descends it draws the cord over a pulley and raises the negative just one half the distance travelled by the positive. When the wires are properly connected and the carbons are in position, the top holder may be allowed to run down until the two carbons meet. This establishes the circuit and excites the axial magnet in the bottom of the case, when the core is drawn into the helix, and the two carbons, through the medium of levers, are drawn apart until the magnetism and tension of the spring balance each other; and as the carbon is burned away the arc is lengthened, the magnetism reduced, when the core is drawn out of the spool, thus feeding the carbons together as they are consumed until the parts have reached a position where the ratchet on the lower lever is beyond the reach of the pawl; then the core descends and the ratchet revolves, when the carbons take a new position, and the feeding goes on as before. The ratchet wheel is prevented from turning more than one tooth at a time by a spring at the end of the lower lever. The pull of the rack is opposed to the spring, and when the pull is reduced by the disengagement of a ratchet tooth the lever, and with it the ratchet, are forced downward, and the succeeding tooth is caught on the pawl. The core on which the magnetism operates is connected with the rack by

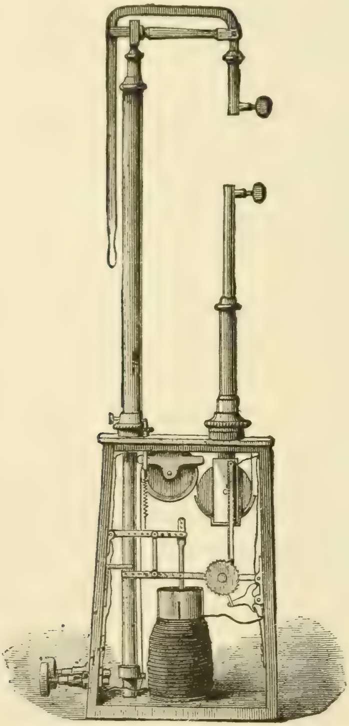


Fig. 41.

compound levers, so that by changing the position of the connecting link the leverage can be readily adjusted.

Adjustments may also be made with the thumb nut on the top of the case, which is attached to a retractile spring. While this lamp is not so susceptible of a very fine adjustment, still, for some purposes, it is better than the more expensive one just described. In places where the speed of the dynamo machine varies much, or where the machine is of poor quality, it is better than the regular clock work lamp.

A new lamp, which is quite different from anything before made, is shown in fig. 42. This lamp is in two parts, connected by vertical tubes. The upper portion has a device for feeding the carbons, and the lower portion contains a device for separating them. The focus or source of light is always at the same place, as the two carbons feed exactly in proportion to the rapidity with which they are consumed. This lamp will accommodate itself to widely varying currents. Should a slackening of the speed allow the carbons to come completely together, they would at once draw apart on the increase of speed, and they will do this any number of times in succession; or the current may be broken and established any number of times without disarrangement of the parts. This feeding has positive movement, and is so nicely balanced that a very slight change in the length of the arc allows the carbons to feed, and should the current be broken, the lower carbon, by a very rapid movement, reëstablishes it before the heat of the carbons is perceptibly diminished, and before the magnetism of the machine is discharged.

The light from the naked carbon points is dazzling to the eyes, and casts very distinct shadows. The light is of wonderful intensity. To diffuse the light without reducing it very much, and to make the small point appear as large as possible, have been the aim of the inventor in constructing this lamp. Above the focus is a silvered reflector, of suitable shape to throw the beams that would be wasted above in a horizontal or downward direction, and from this reflector two rows of prisms are suspended. One half of the prisms are arranged with their flat side to the light, and the other half have their angular side toward the light. Below the focus is a bowl shaped glass, having a zone ground just wide enough to be always between the eye of a near observer and the luminous arc. The point from which the light is emitted appears from a distance diamond

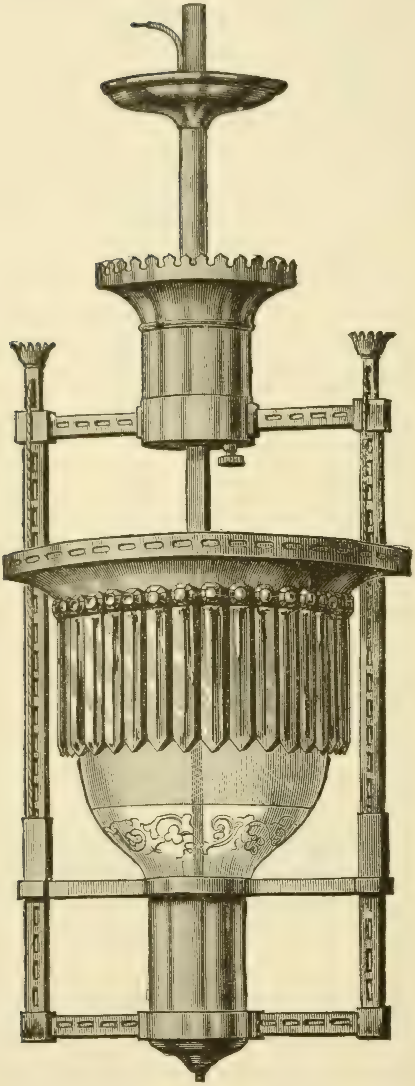


Fig. 42.

shaped and quite large. Thus modified, the light can be looked at with perfect ease, while its brilliancy does not seem to be at all impaired, the ground glass portion of the globe only being between the eye and the luminous point. The prisms and glass bowl enclose the light and protect it from the wind. The bowl is suspended by two cords that pass over pulleys and are attached to the reflector. By pulling the bowl downward the reflector is raised up, thus opening a space through which the carbons may be viewed. A pair of carbons $\frac{3}{8}$x$\frac{3}{8}$ inch in these lamps last about three hours, and afford a very steady light. Carbons $\frac{5}{10}$ x 1$\frac{1}{4}$ inch last about ten hours.

Electric light may be utilized in two ways—either by powerful foci illuminating at great distances, or by less intense foci, giving a more diffused light, suitable for all kinds of night work; thus including lighthouse service, fortifications, maritime service, stores, armies in action; and for manufactories, show rooms, open air use, large workshops, railroad depots and yards, wharf work, steamboats, mines, theatres, large halls, reading rooms, streets, squares, and many other places. For these purposes electric light is superior to all others and much cheaper. Mechanical workshops have been among the first to make use of the electric light, also dyers and sugar refiners, who need a very pure and white light, and spinning mills and foundries have adopted it.

In the matter of street illumination by electricity Paris originally took the lead of the world, though she has since been surpassed by many other cities both in the United States and Europe. The early development of the Paris system, however, gave it a degree of importance which has not been equalled elsewhere, and we therefore present the following interesting description of it, written by Frank L. Pope, Esq., on the occasion of his visit to the Paris Exhibition, in 1878.

There are at the present time some three hundred electric lamps nightly in successful operation, illuminating the boulevards, gardens and public buildings of Paris, and arrangements for lighting all the principal boulevards and places are now in progress.

The magneto-electric apparatus employed is a Gramme machine, arranged for producing alternating currents, the field of force being fed by a smaller machine of the continuous current variety. The candle employed is the double carbon construction of Jablochkoff. Owing to the peculiar arrangement of this alternating machine, it is possible to divide the current so as to furnish sufficient electricity to sixteen, or more, separate candles. That this system, in a scientific and practical point of view, is literally a brilliant success is sufficiently evident to any one who has carefully watched its operation, night after night, in the streets and public places of Paris. The quality of the light is pure, soft and white, the general effect being not unlike that of an unusually powerful moonlight, but differs from the latter in the absence of the heavy, black shadows. These are avoided, partly by placing the candles within globes of opal glass, and partly by placing the lamps at a considerable elevation above the ground, perhaps twenty feet or more. The gas-lights in the vicinity of the Place de l'Opera present an unusually red, smoky and flickering appearance in contrast with the absolute clearness and steadiness of the electric light. That the system is equally successful in an economical point of view, in some of its applications at least, would seem to admit of very little doubt. It is possibly premature to assert that it is destined speedily to supersede the employment of gas for all purposes of public and general illumination on a large scale, yet it must be said that such a result seems exceedingly probable.

The construction of the alternating current magneto machine will be understood by reference to figs. 43 and 44, the former being a longitudinal vertical section taken in the plane of the dotted line A B C, in fig. 44 and the latter an end elevation (partly in section) of the same. An exterior induction ring or armature of soft iron is securely bolted to the frame of the machine, and is wound with insulated copper wire in eight sections, each of which consists of four coils or subsections, *a b c d* (see fig. 44). By reference to the figure it will be seen that the wire, although continuous, is wound in the reverse direction

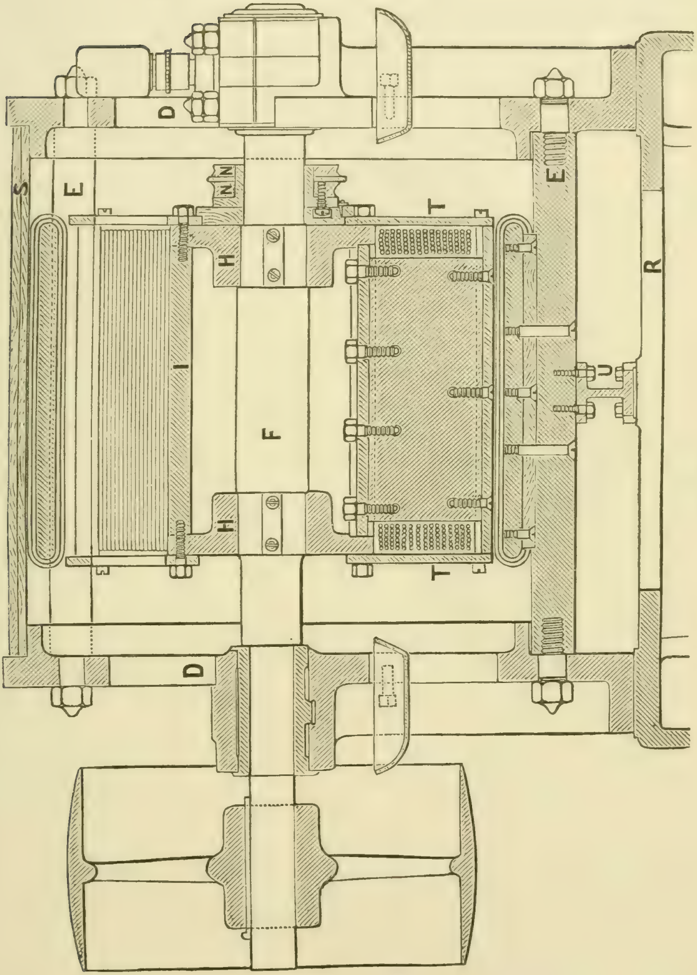


Fig. 43.

upon each alternate one of the eight sections. The inducing magnet T revolves within the induction ring, and consists of eight soft iron cores, K K, etc., projecting radially from a central hub, H, which is fixed upon a horizontal axis, F, revolving in bearings, and provided with a pulley, which receives its motion from a belt driven by steam or other power. Like the sections of the external ring, these radial cores are alternately wound with right and left handed coils. The outer poles of the cores are fitted with enlarged projecting pole pieces, as seen in fig. 44, in

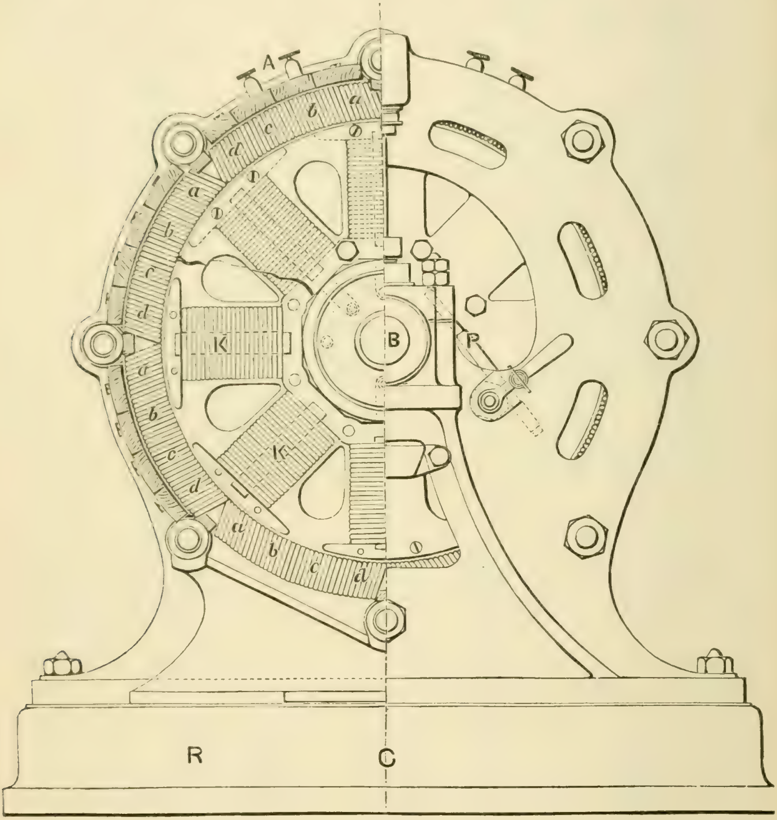


Fig. 44.

order to increase the effective area of the magnetic field, by means of which the electric currents are generated. The revolving compound radial magnet, when the machine is in operation, is magnetized to saturation by the current from a small continuous current Gramme machine of the ordinary well known type, which is driven from the same motor. The same result might, of course, be produced by the action of a voltaic battery of sufficient power. This inducing current is conducted to the revolving magnet by means of brushes of silver plated copper wire, P, pressing upon insulated rings of copper upon the shaft to which the terminals of the magnet coils are connected. It will be observed that by this arrangement the pole changing commutator, which is the most fruitful source of electrical and mechanical difficulty in the ordinary magneto machines, is entirely done away with, and to this feature no doubt the practical success of this machine is very largely due.

It has been stated that the eight sections of the soft iron armature are each provided with four coils or subsections, *a b c d*, all wound in the same direction. The object of this arrangement is to enable a division of the current to be effected by connecting the coils in various ways, the ends of the latter being brought to terminals or binding screws on the outside of the machine. By properly connecting these terminals, the current produced by the machine may be divided into four, eight, sixteen or thirty-two circuits, as desired. For example, if it is required to obtain four currents for four different lamps, it is only necessary to connect in one series all the coils marked *a*, for the first circuit; all marked *b*, for the second circuit, and so of the other two.

The principle of operation of the machine is, of course, sufficiently obvious. When the shaft, with its radial magnet, is made to revolve, powerful alternating currents are induced in the coils surrounding the soft iron ring or armature, the electro-motive force of which depends upon the intensity of the magnetism in the revolving magnet and upon the rapidity of its revolutions.

There are at present three sizes of this machine made, of which the one shown in the illustration is the largest. The weight, capacity, and other particulars of these are shown in the following table:

Particulars of Machine.	Size of Machine.		
	1	2	3
Motive power required (horse power)	16	6	4
Revolutions per minute	600	700	800
Weight of machine (kilogrammes)	650	280	190
" " copper wire (kilogrammes)	103	40	28
Number of Jablochkoff candles operated	16	6	4
Cost of machine, including small continuous current machine (francs)	10,000	5,000	3,500

The dimensions of the machine shown in the figures are as follows: Length, including shaft and pulley, thirty-five inches, width thirty inches, and height nearly the same. The extreme size of the base plate is twenty-eight inches by thirty, and as the drawings are made to scale, the dimensions of any of the other parts of the machine may be estimated without difficulty.

It will be seen that the power required is one horse power for each electric candle, each candle being calculated to be equal to one hundred ordinary gas burners. I was informed that the results of the operation for one year, at the Magazin du Louvre, showed that this estimate is very nearly correct. Several hundreds of these machines have been at work in Paris during the past year, and so far as my inquiries extended, I could not learn that any of them had required repairs or had involved any expense whatever, except that of lubrication.

I was informed that M. Gramme was at work on another and still smaller machine, intended to supply two candles only, which is quite different in construction from those which have just been described, and from which he expects to realize a material saving in the relative expense both of first cost and power consumed in running. There is also a Gramme machine shown in the Exposition which weighs four hundred and forty-one pounds, and is said to produce a light equal to thirty thousand candles, the cost of which is only about 1,500 francs. For practical purposes, however, this model is not considered a good one, as it is much more liable to get out of order than the standard pattern.

The electric candle of M. Paul Jablochkoff, which is so extensively employed in electric lighting in Paris, in connection with the magneto-electric apparatus of M. Gramme, is a very simple device; so simple, indeed, that, as is frequently the case with the most important and most original inventions, the first sensation upon seeing it is one of wonder that nobody ever thought of it before.

The invention consists simply in placing two carbon pencils side by side, and insulating them from each other by means of a thin plate of some refractory material inserted between them, which is a non-conductor at ordinary temperatures, but which becomes a conductor when fused by the action of a powerful current. The most suitable material yet discovered for this purpose is plaster of paris, which is used in all the candles now in operation. One of the results of the use of this material is to impart to the light a faint tinge of rose color, which is by no means unpleasant to the eye.

Referring to the illustrations, a description of the candles and the method of using them, as employed in Paris, will now be given. Fig. 45 is a representation, half in elevation and half in section, of one of the lanterns in the Avenue de l'Opera. Each lantern contains four candles, which are brought into operation successively, only one candle burning at a time. This is necessary in order to keep up the light for the required length of time each night, a single candle as now made lasting only one and a half hours. Fig. 46 is an enlarged sectional view, showing the candles and devices for holding them in position. These are mounted upon a circular base of white onyx, A, which serves not only to support the parts, but to insulate them from each other. The four candles are placed in a corresponding number of clips or candle-holders, arranged in the form of a cross. The candles are surrounded by a globe of white opal glass, sixteen inches in diameter.

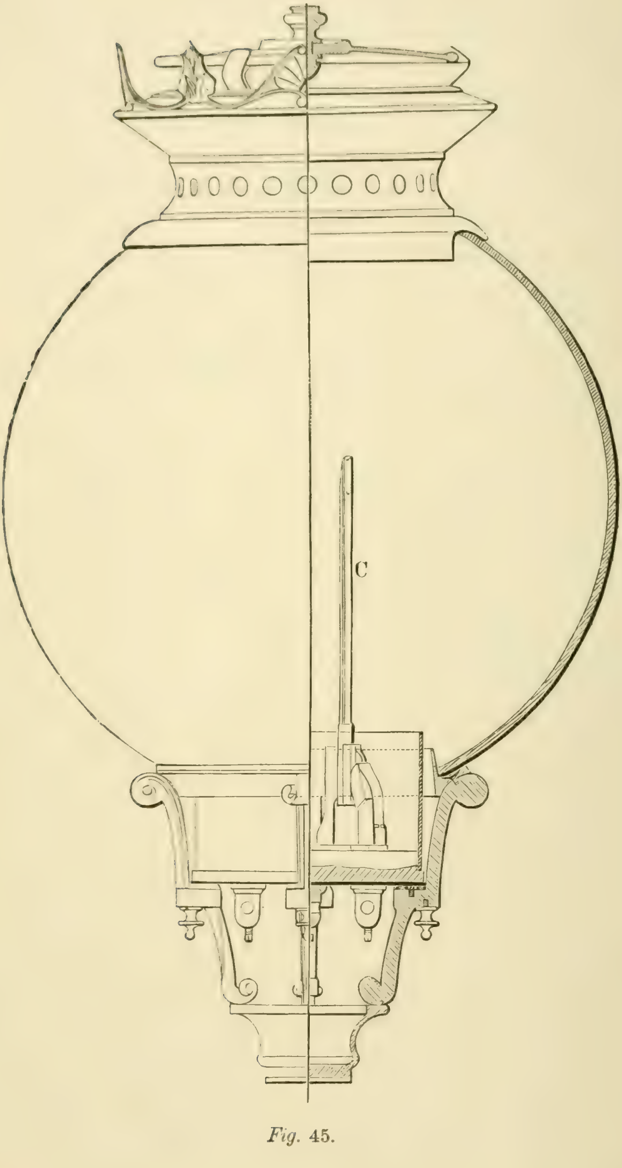


Fig. 45.

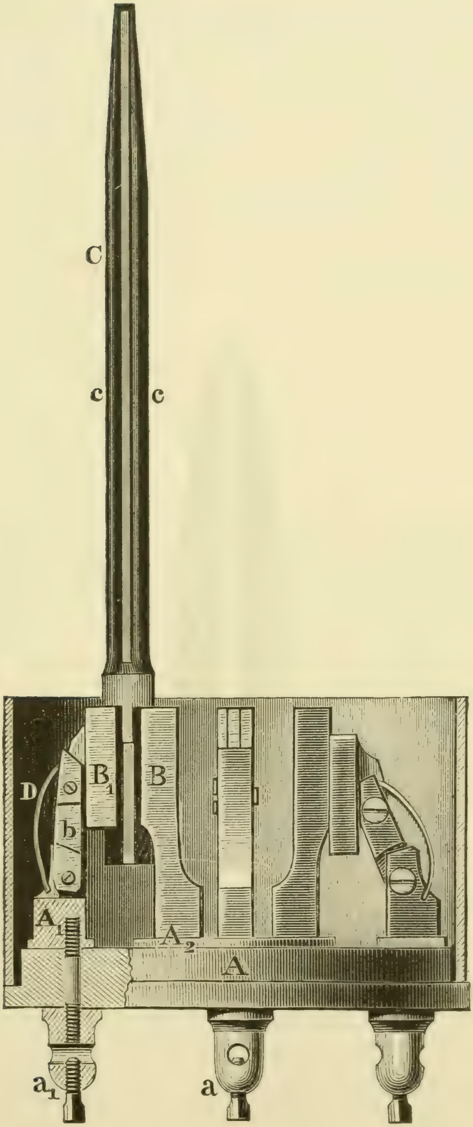


Fig. 46.

The candle itself is shown on a small scale in fig. 46. The two cylindrical pencils of compressed carbon, *c c*, are each two hundred and twenty-five mm. (8·8 inches) in length and four mm. (0.157 inches) in diameter. The distance apart is three mm. (0.118 inches). Fig. 47 shows the tip of a candle of its natural size, in elevation and in section. The candle holder or clip consists of two jaws, B B^1 (fig. 46), one of which, B, is fixed, and the other, B^1, is movable. The opposite faces of these jaws are provided with vertical grooves of semicircular form, for grasping the candle. The four fixed jaws, B, in each lantern are mounted upon a common metallic base plate, A^2, to which the positive pole of the circuit is connected by means of a binding screw, *a*. Each movable jaw, B^1, is jointed by means of a link, *b*, to a block, A^1, which is provided with a binding screw, a^1, to which the negative conductor is attached. A spring, D, presses the movable jaw B^1 against the candle C, and holds it firmly in position. A small metallic plate is attached to the lower end of each carbon pencil on opposite sides of the candle, in order to form a proper electrical connection with the holder. By this simple and effective arrangement the burned out candles may be

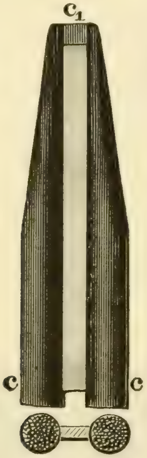


Fig. 47.

replaced by new ones almost in a moment. There are, of course, four of these movable jaws in each lantern, each having its separate binding screw.

The arrangement of the electric circuits is as follows: Referring to fig. 44 it was stated that four distinct currents might be derived from the alternating magneto machine. Each of these currents is capable of supplying four candles at a time, when placed in series in the circuit, for the reason that, at the high temperature produced by the action of the light, plaster of paris fuses and becomes a tolerably good conductor of electricity. A conductor leads from the positive terminal of the machine to an ordinary lever switch, placed in the base of the lamp post, and accessible by a small door. This switch turns on to five points, four of which are connected respectively with the four movable jaws B^1, of the candle holders, while the fifth connects with the return wire leading from the central binding screw *a*. This switch thus serves to direct the current to any one of the four candles, or, if necessary, to cut out the whole arrangement. The return wire from the binding screw *a* leads to the next lamp post, and from that in a similar manner to the next, and so on through the four, after which it returns to the negative terminal of the machine. Three other circuits from the machine are arranged in the same way, so that when in operation there are four distinct circuits, with four lights in each circuit, or sixteen lights in all.

Fig. 48 will serve to give an idea of the general arrangement of the apparatus. The alternate current magneto machine, which supplies the current for operating the lamps, is seen at the lower right hand corner of the figure, to the left of which is the continuous current machine which supplies the field of force. The arrangement of the switch in connection with the circuits leading to the four candles will be readily understood from the figure.

The conductors used are constructed of a strand of seven No. 18 B. W. G. wires, of tinned copper, twisted together, and have a resistance of about one ohm to one thousand four hundred feet. These conductors are insulated with strips of india rubber, several thicknesses of which are wound on spirally and united by india rubber cement. These are placed underground, in tubes similar to the vitrified drain tile used in this country. Some arrangement of insulators (which was not seen) is employed to keep the wires from touching the interior of the pipes.

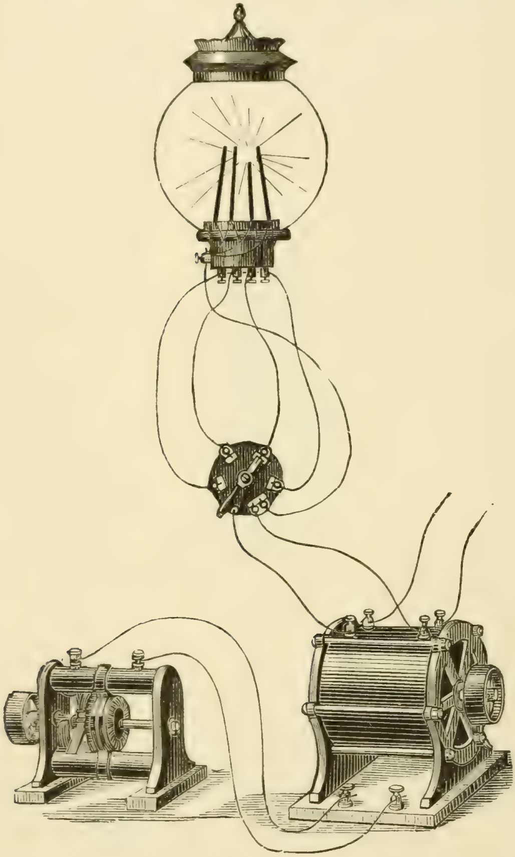


Fig. 48.

It should have been mentioned in its proper place, that each candle is provided with a conducting tip, as shown as c_1 in fig. 47, consisting of a piece of powdered plumbago and gum, compressed into a little cylinder about as large as a No. 18 wire, and attached to the candle by a strip of asbestos. The object of this is to complete the circuit when the machine starts, and maintain it until the fusion of the plaster of paris commences, when the latter becomes sufficiently conducting, as before mentioned.

The number of lamps now in operation in the Place de l'Opera and the avenue of the same name is forty-six; but as the two lamps directly in front of the opera house are arranged to burn two candles at a time, in order to increase the brilliancy of the illumination, it will be seen that forty-eight candles are in operation at once. The average distance apart of the lamps on each side of the avenue is about one hundred and fifteen feet. These forty-eight candles are fed by three separate machines of the kind which has been described. The greatest distance to which the current of any one machine is transmitted is said to be two hundred mètres (about six hundred and fifty feet). At first it was necessary to employ a man to go round to the different lamp posts at intervals of an hour and a half, and switch the current to a fresh candle as the old one burned out; but an automatic apparatus has been invented for doing this, which is now being applied, and which will be understood by reference to fig. 49. A and A_1 are two candle holders, in which are placed the candles C C_1. An upright angular lever, L, is pivoted to a standard, l_1, upon the base. A spring, *s*, presses against this and tends to throw it into such a position as to bring the short arm *l* of the lever into contact with the metallic block *m*, but this movement is prevented by a platinum wire, *w*, which is attached to the top of the lever L, and rests against the insulating portion of the candle C, at a point near its socket. This arrangement forms an automatic shunt, for when the candle C is burned down far enough to release the wire *w*, the spring *s* throws the lever L over, making contact between *l* and *m*, and thus bringing the candle C_1 into circuit. This is in like manner arranged to bring the third candle into circuit at the proper time, and so on. The substitution of one candle for another produces scarcely any visible interruption of the illumination.

A few words in reference to the cost of illumination by this system may be of interest by way of conclusion. The items of expenditure, other than that of interest on first cost, are almost entirely for motive power, candles and attendance. The cost of Jablochkoff candles is given as about fifteen cents each. Mr. Stayton, who examined the apparatus and system in Paris, in behalf of the vestry of Chelsea, a parish of London, gives the total running expense of thirty-two candles as sixteen shillings (nearly four dollars) per hour. His estimate includes wages, coal, oil, waste, etc., as well as electric candles. This would make the expense per light per hour about twelve cents.

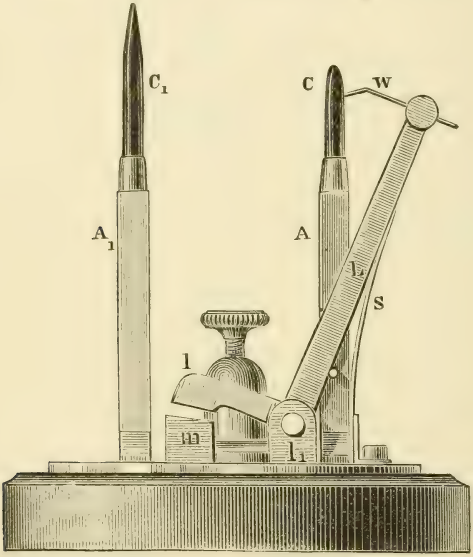


Fig. 49.

The system now in operation in the Place and Avenue de l'Opera was put up under a contract with the director of public works in Paris, by the General Electricity Company, which undertook to provide all the apparatus, and light the lamps for a term of six months, covering the period of the Exposition, for one franc and forty-five centimes (twenty-nine cents) per light per hour. The amount of light produced by each electric candle is variously stated from five hundred to seven hundred wax candles.

The principal difficulties in the way of the general adoption of this light for street purposes, aside from the original outlay, which is a pretty serious item, is the amount of power required for each lamp, and the difficulty of conveying the current to any considerable distance from the machine without seriously reducing its strength. These are really the same difficulties in two different forms. At present, however, it certainly seems admirably adapted for lighting large squares, places and public buildings, and it does not seem unreasonable to expect that it will ere long be utilized for other purposes, when we consider what a number of inventors, some of them of exceptional ability, are now at work upon the problem.

Another machine for use in electric lighting, and somewhat resembling the Brush machine in construction, has just been brought out in France, and is highly spoken of there. One of these machines, with eight magnets only (of the same dimensions as those in the Alliance machines), will, it is said, illuminate from three to four of the Jablochkoff candles with an expenditure of but little over one horse power for driving purposes. This is considerably better than the Gramme. It gives reversed currents and experiences scarcely any heating. Its dimensions, besides, are very small, and the elementary parts simple in construction and easy of adjustment. A description of this machine, for which we are indebted to the Telegraphic Journal, is given below:

The enhanced effect of this class of machines is due to the fact that to the induction currents produced in the coil of the Gramme machines are added those produced in ordinary magneto-electric machines.

In order to understand this, let us imagine a Gramme ring, fig. 50, divided, for example, into four sections, insulated magnetically the one from the other, and forming, consequently, four electro-magnets, placed end to end. Let us suppose that the iron core of each of these sections is terminated at each end by a piece of iron, A B, forming expanded prolongations of the poles; and let us suppose all these pieces to be joined by pieces of copper, C D, to form one solid ring, around which are placed permanent magnets, N S, with poles alternating with each other.

Let us examine what will take place when this ring accomplishes a revolution upon itself; and let us see, in the first place, what will happen on the approximation of the expanded pole B, as it travels from left to right, to the pole N. At this moment it will develop in the electro-magnetic helix an induced current,

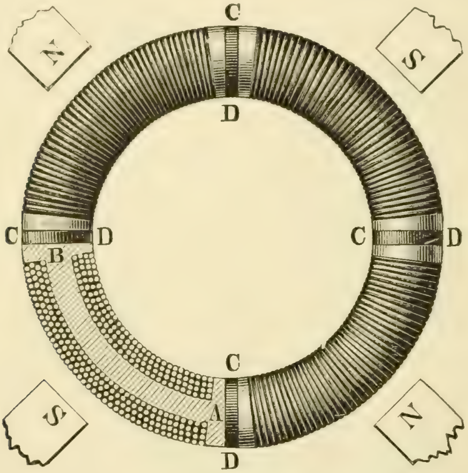


Fig. 50.

as in the Clark machine. This current will be instantaneous, and in a contrary direction to the Amperian currents in the inducing magnet. It will be very powerful, by reason of the proximity of B to the pole N; but the ring, in passing on, causes a series of magnetic displacements between the pole N and the core A B, which give rise to a series of currents, which may be called currents of polar introversion, from B to A. These currents will be direct in relation to those in N, but they are not instantaneous, and they increase in energy from B to A.

To these currents will be joined simultaneously the currents (of dynamic induction) resulting from the passage of the helix before the pole N. When A leaves N a demagnetization current is produced, equal in energy, and in the same direction, as the magnetization current due to the approximation of B to N. Thus we get reverse induced currents through the approach and recession of B and A; direct induced currents during the passage of the core A B before the inductor; direct induced currents resulting from the passage of the helix in front of N. All these inductive effects are thus accumulated in this combination; there are also currents resulting from lateral reaction of A B upon neighboring poles.

To still further augment the effects of induction, M. de Méritens, the inventor, makes the core and appendages of thin plates of iron, cut out and placed together, to the number of fifty, each one millimètre thick. The coils are so arranged that they can be connected in series or for quantity.

In fig. 50 we have considered only four sections, but there are, in fact, more than this; the model to which we have referred possessing sixteen, which are mounted on a bronze wheel, centred on the motor shaft. The inductor magnets are placed above the wheel and strongly fixed horizontally to two bronze frames.

A little consideration will show that the ring is constructed under the best possible condition. In fact, as each section is separate, it may be dismounted singly, and consequently, the wire can be wound on without difficulty. Those who know the difficulty of winding a Gramme ring will readily appreciate this advantage. On the other hand, the core being composed of plates which can be at once removed by releasing the key piece is an enormous advantage, for it obviates the precision necessary to the construction of solid rings, which are always difficult to keep perfectly true. Lastly, there is neither commutator nor collector, and, consequently, no loss of current.

We have said that this machine can feed three or four Jablochkoff candles applied to an electric light regulator; but it has also been found competent to illuminate regulators, even when the carbons were separated by a distance of three and a half centimètres. It is certain that these results are very important, and we may safely argue a future for this machine.

As is well known, when an electrical current, which flows through a conductor of considerable length, is suddenly broken, a bright flash, called the extra spark, appears at the point of separation. The extra spark will appear, although the current is not sufficient to sustain an arc of any appreciable length at the point of separation.

In the system proposed by Professors Thomson and Houston, one or both of the electrodes, which may be the ordinary carbon electrodes, are caused to vibrate to and from each other. The electrodes are placed at such a distance apart that in their motion towards each other they touch, and afterwards recede a distance apart which can be regulated. These motions or vibrations are made to follow one another at such a rate, that the effect of the light produced is continuous; for, as is well known, when flashes of light follow one another at a rate greater than twenty-five to thirty per second, the effect produced is that of a continuous light. The vibratory motions may be communicated to the electrodes by any suitable device, such, for example, as mechanism operated by a coiled spring, a weight, compressed air, etc.; but it is evident that the current itself furnishes the most direct method of obtaining such motion, as by the use of an automatic vibrator or an electric engine.

In practice, instead of vibrating both electrodes, it has been found necessary to give motion to one only; and since the negative electrode may be made of such size as to waste very slowly, motion is imparted to it in preference to the positive. The carbon electrodes may be replaced by those of various substances of sufficient conducting power.

In this system, when desired, an independent battery circuit is employed to control the extinction and lighting of each lamp.

The following is a description of one of the forms of the electric lamp devised to be used in connection with the system.

A flexible bar, *b*, of metal, fig. 51, is firmly attached at one of its ends to a pillar, *p*, and bears at its other end an iron armature, *a*, placed opposite the adjustable pole piece of the electro magnet *m*. A metal collar, *c*, supports the negative electrode,

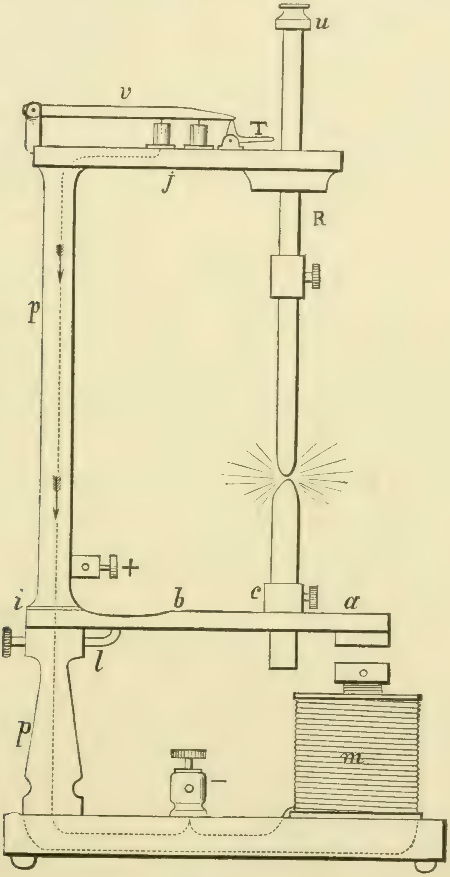


Fig. 51.

the positive electrode being supported by an arm, *j*, attached to the pillar *p*.

The pillar *p* is divided by insulation at *i* into two sections, the upper one of which conveys the current from the binding post marked +, to the arm *j*, and the rod R, supporting the positive electrode. The magnet *m* is placed, as shown by the dotted lines, in the circuit which produces the light. The pillar *p* is hollow, and has an insulated conducting wire enclosed, which connects the circuit closer *c* to the binding post marked —. The current is conveyed to the negative electrode, through *b* and the coils of the magnet *m*. When the electrodes are in contact, the current circulating through *m* renders it magnetic and attracts the armature *a*, thus separating the electrodes, when, on the weakening of the current, the elasticity of the rod *b* again restores the contact. During the movement of the negative electrode, since it is caused to occur many times per second, the positive electrode, though partially free to fall, cannot follow the rapid motions of the negative electrode; and, therefore, does not rest in permanent contact with it. The slow fall of the positive electrode may be insured either by properly proportioning its weight, or by partly counterpoising it. The positive electrode thus becomes self-feeding.

The rapidity of movement of the negative carbon may be controlled by means of the rigid bar *l*, which acts, practically, to shorten or lengthen the part vibrating.

In order to obtain an excellent, but free contact of the arm *j* with the positive electrode, the rod *r*, made of iron or other suitable metal, passes through a cavity, *s*, fig. 52, filled with mercury, placed in electrical contact with the arm *j*. Since the mercury does not wet the metal rod *r*, or the sides of the opening through which it passes, free movement of the rod is allowed without any escape of the mercury. We believe that this feature could be introduced advantageously into other forms of electric lamps.

In order to prevent a break from occurring in the circuit, when the electrodes are consumed, a button, *u*, fig. 51, is attached to the upper extremity of the rod R, at such a distance that when the carbons are consumed as much as is deemed desirable, it comes into contact with a tripping lever, *t*, which then allows two conducting plugs, attached to the bar *v*, to fall into their respective mercury cups, attached, respectively, to the positive and negative binding posts by a direct wire. This action practically cuts the lamp out of the circuit.

Another form of electrical lamp, devised recently by M. Reynier, is shown in figs. 53 to 56. The action of this lamp is based upon the well known principle that if a very intense current of electricity be led through a resisting and refractory conductor, such as a pencil of carbon, the temperature of this conductor may rise to a dazzling white heat, and it will then emit a vivid light. The principal difficulty to be overcome in the electrical lamp is to limit the undue waste of the luminous conductors—a waste which is very rapid, even in an enclosed space, on account of the volatilization and disaggregation of the carbon pencils; and which is greatly accelerated in the open air by the rapid combustion of the incandescent carbon.

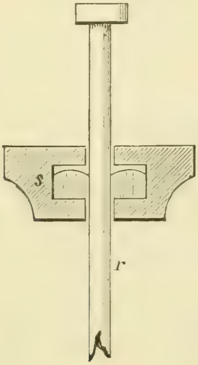


Fig. 52.

In the various systems of electrical lamps with continuous conductors heretofore proposed, the renewing of the carbon points is performed in the following manner: The incandescent pencil is placed in the circuit, with fixed contacts, and remains part of the same until broken by being consumed. The light is then extinguished. The current now suddenly passes from this carbon to another, which is consumed, the circuit broken in its turn, and so on.

This method is open to many objections; there is an interruption of the current, accompanied by an extinction of light at every rupture of the pencil. The luminous intensity varies continually on account of the gradual thinning of the carbon. The conductor only gives its maximum of light at the moment next to that of rupture. Finally, the proposed apparatus can scarcely work except in an enclosed space.

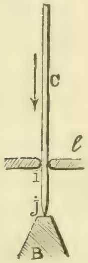
In the new system here referred to the renewal of the carbon is progressive. The carbon, incandescent a part of its length, advances almost continuously, till the whole available part has been consumed. The system can operate in the open air. The following is the principle: A cylindrical or prismatical pencil of carbon, C, fig. 53, between *i* and *j*, forms part of an electrical circuit (continuous or alternate), sufficiently intense to render this part incandescent. The current enters or leaves at the point of contact *l;* it leaves or enters at the point of contact B. The contact *l*, which is elastic, compresses the pencil laterally; the contact B touches it at its end. Under these conditions the carbon is consumed at its extremity sooner than at any other place, which tends to diminish its length. Consequently, if the carbon is steadily forced in the direction of the arrow, it will gradually advance as it is consumed, sliding through the lateral contact *l*, so as to press continuously on the point of contact at B. The heat developed by the passage of the current is greatly increased by the combustion of the carbon.

In practice, a revolving contact, B, fig. 54, which carries off the cinders of the carbon, is substituted for the fixed contact. The rotation of the contact is made dependent on the progressive movement of the carbon, so that the weight of the latter, exerted at its end, acts as a brake on the mechanism of the motion.

The principle of this new system once established, simple apparatus to realize it could easily be devised. The specimens submitted to the Society of Physics may be understood at the first glance. The advance of the carbon C, fig. 55, and revolving contact at B, are obtained by means of the descent of the heavy rod P. To wind up the lamp it is only necessary to raise this rod. The carbon pencil is placed in its position without any adjustment. The luminous point remains fixed, which is always advantageous, and particularly so in optical experiments.

This apparatus gives a clear white light with four Bunsen elements. With a more powerful electrical source, several lamps of this system may be operated, and thus "a subdivision of the electrical light may be obtained."

Fig. 53.



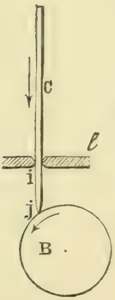


Fig. 54.

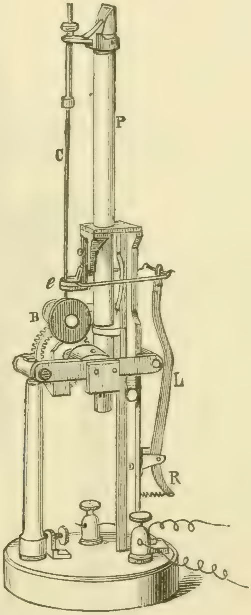


Fig. 55.

The following experiments were made before the Society of Physics: With a battery of thirty-six elements of eighteen centimètres, grouped in two series of eighteen each, four lamps were operated when placed in a single circuit, and all four were repeatedly extinguished and relighted at will. Each of the four lamps could be extinguished and relighted "individually," the three others continuing unaffected. Light was also obtained from one of these lamps by means of the current of a small Gramme machine, for the laboratory, with treadle attachment.

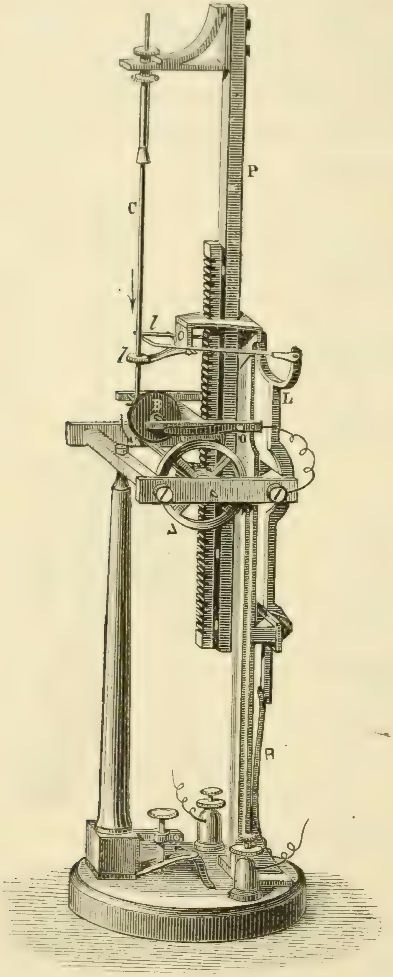


Fig. 56.

Finally, a light was obtained with a battery of three Planté (secondary) elements, which were charged during the afternoon, at the establishment of M. Bréguet, and carried, charged, to the hall of the society. This experiment may be considered as a step towards the application of the electrical light to domestic purposes.

The following is a more recent arrangement of the apparatus:

In this arrangement the revolution of the turning contact is obtained from the tangential component of the pressure of the carbon pencil on the circumference of the disk. Thus the end of the pencil never leaves the revolving contact, and all causes of irregularity in the light are obviated.

The brake, always indispensable, is operated, fig. 56. in the following manner: The disk B is carried by a lever swinging from O. The pressure exerted by the carbon on the disk B causes the shoe S to press on the face of a wheel, A, which is revolved by means of the weight of the heavy rod P through its rack and the pinion *a*. Accordingly as the point of the luminous conductor presses more or less heavily on the disk, the brake will retard, more or less, the descent of the heavy column, which occurs at almost inappreciable intervals.

A great deal has been said lately about the substitution of the electric light for gas, and from the frequent remarks which we hear on this subject it would appear that no small portion of the popular mind inclines to the belief that the realization of this event on an extended scale is not far distant. It should, however, be remembered that the great advantage of the electric light, so far at least as economy is concerned, can be obtained in the highest degree only where a large quantity of light is wanted, and that the circumstance under which the light is to be used has a modifying influence in regard to its application. A place already provided with power, or in such a position as to receive it without necessitating extra provisions for the purpose, would, of course, be served more economically than another requiring the special introduction of machinery and the employment of help to look after it. As the amount of light required decreases, the economy also becomes very much less marked.

Platinum and iridium, as already explained on page 32, and gas retort, or other carbon pencils when rendered incandescent by the passage of sufficiently powerful currents, serve very well for illuminating small spaces and apartments, but the difficulties attending the use of these substances are considerable, and no extended practical application of them, so far as we are aware, has yet been made. The subject has, however, been taken up anew by Messrs. Edison, Sawyer and Man—the former working independently and the two latter together—and the results so far obtained, it is said, promise very well for their ultimate success.

Considered from a theoretical standpoint alone, carbon is even better adapted for lighting purposes than platinum or iridium, since its radiating power for equal temperatures is greater and its capacity for heat, referring, of course, to equal volumes, is less than that of either of these metals; thin sticks of this material would consequently be raised to a much higher temperature for a given current than equal volumes of the metals. Carbon also possesses the advantage of remaining intact at the highest temperature, while the metals become fused and are even deflagrated; its disadvantage, on the other hand, aside from a tendency to volatilize at high temperatures, is the ready combination of its heated particles with the oxygen of the air, but this in a measure has been overcome by confining the incandescent carbon in an atmosphere of some non-oxidizing gas, such as nitrogen. The Sawyer-Man lamp comprehends the use of this gas for the above mentioned purpose, but the idea is certainly not a new one. We shall refer to this lamp again presently.

It having been announced a few years ago that Mr. Edison had discovered a means for subdividing the electric current indefinitely, thereby making it possible to use electricity for lighting small areas, the statement had a marvelous effect in bringing down the value of gas stock abroad.

It is somewhat remarkable, too, that although gas shares depreciated greatly and suddenly in England, on this announcement, few persons in that country had the slightest idea of what the alleged improvement consisted: they had, however, seen the light, and already knew what wonderful things the American inventor had done in other directions, and that seemed quite sufficient.

In the application of Mr. Edison for a patent on his electric light invention, as it now appears on the records of the English commissioners of patents, bearing date of Wednesday, October 23, 1878, nothing at all is said about the subdivision of the current. The title which expresses the purport of the invention, and which will appear on the face of the patent, is as follows: "Method of, and means for developing electric currents and lighting by electricity." We may, however, assume that the idea is included therein. It will not be out of place in this connection to note, as well, that an application was also filed in the English patent office on October 26, just three days later, by Mr. Charles E. Shea, for a "Method of dividing and distributing the current produced by magnetic batteries and magneto and dynamo electric machines into an indefinite number of separate currents, equal or relatively unequal to each other in quantity or force." How many other persons are engaged upon the same problem it would be difficult to state, but the number is certainly very large. But leaving out of consideration the practicability of the infinite subdivisions of the current, regarding which scientific electricians have well known views that are not likely to be much affected now, we come to the principal part of the invention. More than a quarter of a century ago a good deal was done by inventors in this and other countries toward securing an electric light, by causing a current to pass through a platinum wire, and so raising its temperature as to make it self-luminous. The results at that time fell far short of the expectations of the sanguine experimenters. One obstacle to success was the liability of the wire to fuse. This Mr Edison now claims to have overcome by so applying a small bar that it will expand the instant the wire reaches within a few degrees of the fusing point, and intercept the flow of the current through the wire sufficiently to prevent fusing.

This automatic arrangement secures, it is said, an even temperature in the wire or thin strip of platinum, and consequently a steady glow of pure light. If this is done economically, and the practical limit of the subdivision is sufficiently extended, it is obvious that a marked advance has been made in artificial illumination. Actual trial, however, must determine whether the action of the automatic bar regulator will do all that is claimed for it.

A somewhat similar arrangement, or one which, at first sight, might be thought to involve the same principle, was exhibited before the Royal Society in June, 1878, by Dr. Siemens; and the method with which Mr. Farmer experimented some years since might not appear altogether dissimilar. As early as 1859—nineteen years ago—Mr. Farmer also demonstrated the possibility of subdividing the electric current for illuminating purposes, and at the same time showed its application to private dwellings by actually lighting one of the dwelling houses in Salem, Mass., every evening during the month of July of that year. This was undoubtedly the first private dwelling ever lighted by electricity. The current used for the purpose was supplied by three dozen six gallon battery jars. In 1875, he carried the subdivision still further, by making forty-two divisions in the current from a single dynamo-electric machine, and producing as many separate lights. The machine used in this case did not weigh over eight hundred pounds, and was driven by a small steam engine. While, therefore, a casual observer might discover a marked similarity between the invention of Mr. Edison and those of Messrs. Farmer and Siemens, a more careful one would scarcely fail to note the difference which, in one sense, is quite distinctive. In both of the latter it is the current which is regulated, while in the former it is the temperature of the incandescent substance, each lamp being entirely independent of the strength of current above a certain amount, and each also independent of the other.

The new form of electric light produced by what is known as the Sawyer-Man lamp, has been publicly exhibited in New York lately by the Electro-Dynamic Light Company, and its appearance alone certainly impresses the observer very favorably. We have, however, no reliable data in regard to the photometric value of the lights, the current required for each, nor the practical limit to the subdivision of the principal current. Undoubtedly, subdivision can be carried as far with this form of lamp as with any other that has been brought out—it may be further. But there is a limit for the best—the press to the contrary notwithstanding—as will readily appear when we consider that a certain amount of current, and not a very inconsiderable one either, is required for each lamp. The division of the current itself to almost any extent is no difficult problem for small amounts, it being only necessary to lead off a number of branch circuits from the main conductor, and the current, following Ohm's well known law, will divide between them in the inverse ratio of their resistances; if all are equal, the currents in each will be alike. But when a current sufficient to maintain carbon pencils at a white heat is required in each branch, the practical limitations begin to appear. It is said that by the use of M. Rapieff's system, which has been practically introduced into the London Times' composition rooms, twenty lights from a single machine are obtained, and that the distributing principle has proven a great success.

One great advantage of this light is that it can be sustained for a whole night, if necessary, without change of carbons, or any attendance, and the intensity remains always the same, however much the carbons are consumed. Four carbon pencils instead of two, as in the ordinary form of regulator, are used with the system. These are opposed to each other in pairs, and so placed that the plane of one is at right angles to that of the other. At first the carbons are together, but when the current is sent through them they are drawn apart by an electromagnetic apparatus, which forms part of the lamp, and as the points consume, are made to approach each other slowly. This is effected by means of a lead weight or counterpoise. With carbons twenty inches long and two tenths of an inch in diameter the light is maintained for seven or eight hours, and with carbons twenty-four hundredths of an inch thick it is kept up for nine or ten hours. The light is equivalent to from one hundred to one hundred and twenty gas flames, or about one thousand candles, but a smaller form of the lamp is made which is estimated to give five gas flames. The resistance of the arc is only two or three ohms.

The Sawyer-Man lamp consists of two conductors enclosed in a sealed glass vessel of about eight inches in height by two and a half in diameter, containing nitrogen, and a very thin carbon pencil, probably one tenth of an inch thick and three quarters long, which is the source of the light when rendered incandescent by the passage of the current. Every precaution has been taken in the construction of the lamp to modify or remove even the slightest thing that could tend to interfere with its use in a practical way. The glass is made very clear, to prevent undue absorption both of light and heat; the wires are large and long, so as to form ready conductors for the dissipation of useless heat that is always generated, and, finally, a diaphragm of some non-absorbing substance is placed immediately below the carbon pencil to prevent radiation downward, which, if allowed to take place, might seriously interfere with the sealing. The conductors are also wound in a spiral form to economize space. Considerable secrecy has been maintained by the inventors in regard to some substance contained in the base of the lamps; but this is believed to be metallic potassium, placed there to absorb any oxygen that may chance to leak through.

We have seen five or more of these lamps in operation at one time, and were much pleased with their performance. Our investigation of the various details connected with their construction and practical maintenance was, however, too limited to enable us to judge of them from an economical standpoint. One or two things which came under our observation did not impress us quite so favorably as we had reason to anticipate from what we had heard of them. Possibly a poor adaptation of means to ends, which is so often noticeable with new and hastily introduced apparatus, is in part responsible for this, but it is certainly remarkable that the continuance of the light on the occasion of our visit was not prolonged beyond five minutes at the most; and this fact, taken in connection with the sound from the dynamo-electric machine, which indicated both a high rate of speed and the production of a powerful current, was not calculated to greatly astonish any one familiar with the subject of electric lighting. The particular advantages of this light, however, are its steadiness and the ease with which it can be controlled, both very desirable qualities, and it will no doubt meet with considerable success.

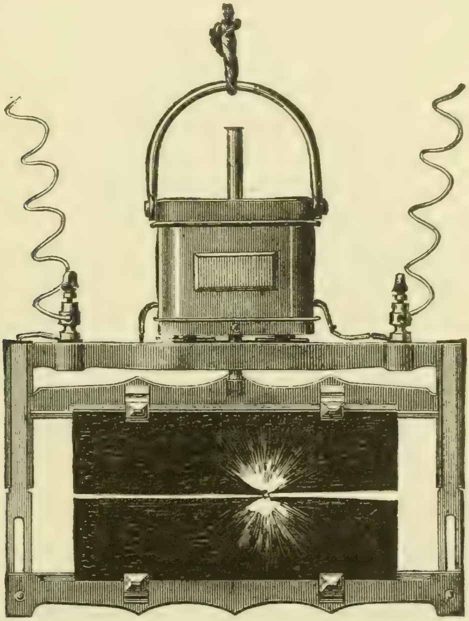


Fig. 57.

At present we have very little reliable data, beyond that given on page 30, regarding the cost of lighting shops and factories in this country, or the use of the light in a small way. What we have there said, however, shows under what conditions the employment of the electric light may be both advantageous and economical.

Messrs. Wallace & Sons, of Ansonia, Conn., have been among the first here to introduce the light in a practical way, and their extensive rolling mills have been very successfully lighted with four lamps for months together. Fig. 57 shows one form of the lamp which they use; it has already been described on page 16. Various other applications of the light have also been made elsewhere in this country, but we are, unfortunately, not in possession of any detailed statement of the cost of the same, compared with that of gas used under similar circumstances.

Mr. Schuyler informs us, however, that the cost of lighting one of the corridors in the Equitable building, New York, by two Maxim lamps, like that shown in fig. 42, and one of the Farmer-Wallace machines, is a trifle over fifteen and a half cents per hour for running expenses alone, as against fifty-one cents per hour for gas, and that the quantity of light furnished by the two lamps, which replace fifty-one gas burners, is three times greater. It is confidently hoped by Mr. Schuyler and his associates that the advantages of the electric light will be even more marked, both as regards steadiness and economy, when the Farmer-Wallace machine is replaced by one of the new Maxim machines, as is proposed to be done shortly. This machine is shown in fig. 58, and, it is claimed, will furnish a very large amount of current for the comparatively small amount of material used in its construction. Its tendency to become heated is, at the same time, very small, on account of the manner of arranging the armature and field magnets, whereby a constant circulation of air among all the parts is secured.

The Maxim machine and lamp, we understand, have been adopted by the Russian government for the steamships which are being constructed for it in this country, the trial on one of the vessels having given so much satisfaction that all will now be similarly equipped.

In England, the Lontin machine and lamp have been somewhat extensively introduced, but it is difficult to get really accurate statements in regard to the cost of operating them. The machine, which has not been noticed in the preceding pages, is constructed in two parts, one of which supplies the current for magnetizing the iron cores of the second, on the principle of the Wilde machine, while the latter is arranged to supply several different circuits containing separate lamps. The lamp is a modified form of the Serrin regulator, though in what the improvement introduced in it by M. Lontin really consists we are not informed. Like the Serrin lamp, it is, doubtless, rather costly. No reliable figures have been published, so far as we can learn, concerning the cost of producing light by this system, but it is believed to be somewhat less than that of the Jablochkoff candle supplied by the Gramme machine, which we have already given as about twelve or thirteen cents per light per hour, not including expense of repairs, depreciation and interest upon original outlay.

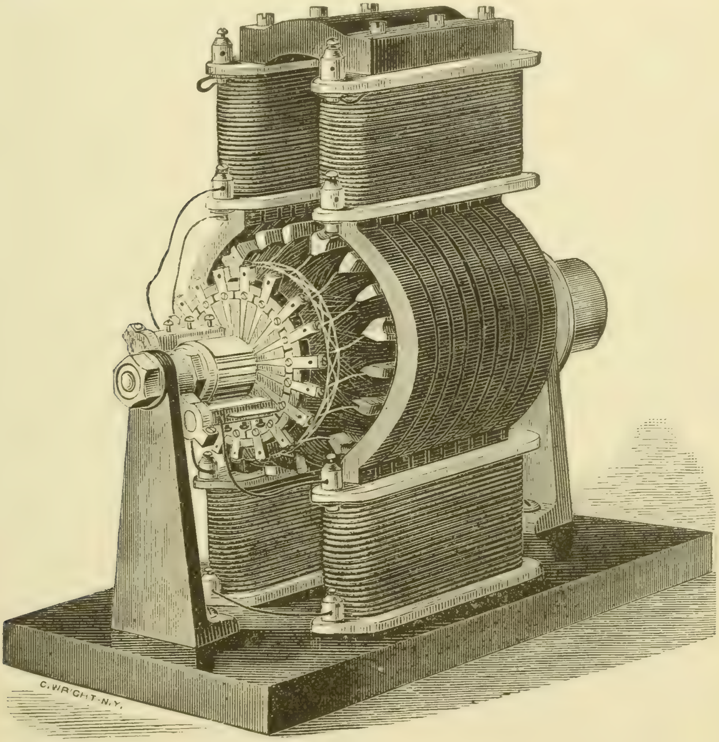


Fig. 58.

It is stated that the lighting of the Gramme workshop, in Paris, a room about forty feet square and sixteen feet high, has been maintained during four or five years past by a single light taking the place of twenty-five burners, and at a cost not exceeding twelve cents per hour.

The Ducommun foundries, at Mulhouse, among many other places abroad, have also been lighted with electricity for the past three years or more, and we refer to them here because of the details which have been made public in regard to the application and use of electricity in this case. One enclosure, about one hundred and eighty-four feet long and ninety-two broad, is lighted by means of four Serrin lamps, supplied from a like number of Gramme machines. The lamps are placed about sixteen feet above the floor, seventy feet apart in the direction of length, and forty-six feet in the direction of width. Scarcely any shadows are given, as the cross rays of the lamps are such, when placed as above, as to illuminate the different parts of the room almost equally well. The total cost of the complete equipment, including machines, lamps and placing of the same for service, amounted to about two thousand dollars, which is near what it would have cost to put in two hundred and fifty gas burners, while the light produced with the present arrangement really exceeds that from four hundred burners.

A comparison of the cost of lighting this foundry by gas and electricity is here given, on the authority of M. Fontaine.

Lighting by Means of Gas obtained from Oil.			Lighting by Means of the Electric Light.		
Power of light expressed in gas burners.	Cost per hour.		Equivalent of the power of the Electric Light from four Regulators, expressed in number of gas burners.	Cost per hour.	
	Without Interest or Deterioration.	With Interest and Deterioration.		Without Interest and Deterioration.	With Interest and Deterioration.
Burners.	Francs.	Francs.	Burners.	Francs.	Francs.
442	11·05	15·03	442	1·54	6·64

From the preceding table it would appear, that with equal light emission, the electric light in this case costs less than gas, in the ratio of about 1 to 2·26, with interest and deterioration, and of 1 to 7·17 without interest and deterioration.

Before concluding the chapter, we should say that the relative cost of gas and electric lighting given above, and which does not appear to differ materially from the cost under similar circumstances in this country, is, after all, only another example of lighting on a large scale, in which case, as before stated, the electric light can be employed to the greatest advantage. For the illumination of small apartments and for private houses, however, where, comparatively speaking, a small light only is wanted, and that at the lowest cost, the foregoing advantages are not so apparent. It would, however, be premature, considering the number who are devoting their attention to this subject, and the consequent rapidly increasing application of electricity as a source of illumination, to assert that this agency may not ultimately be made to yield corresponding advantages on a small scale, though it is none the less evident now that other improvements will first have to be made.

Since the foregoing was put in type we have received a very interesting communication from Mr. Moses G. Farmer, on the subject of electrical lighting, which we give herewith. Its importance in this connection is amply shown in the amount of general information it contains, and which Mr. Farmer's large experience renders him so eminently able to give.

In the summer of 1858, while reading of the very interesting experiments of Prof. Draper on the heat and light evolved by a platinum wire, which was traversed by an electric current, I was struck by the rapid increase in the amount of light given out as the temperature of the wire approached the point of fusion, and it struck me that, if the temperature of the wire could be steadily maintained quite near the melting point, a useful light could be obtained from it. I was not long in devising a combination of electro-magnets, rheostats and batteries that would give the desired result, and early in 1859 I put the idea into successful and practical execution, and we had a beautiful light in use in my house in Salem.

I at once entered upon a protracted investigation of the conditions which govern the management of the current, the construction of rheostats, the arrangement of lamp, etc., and the best proportion of length, width and thickness of the illuminator. I tried various substances in the course of my investigation, such as copper, aluminum, platinum, iridium, palladium, iron, nickel, carbon, etc.

Pure iridium gave the best results of any of the metals. Alloys of iridium and platinum gave next best results, and next to this, platinum and palladium. Carbon, when inclosed in an atmosphere free from oxygen, also gave satisfactory results. Nitrogen, carbonic oxide and hydrogen are all suitable gases to surround the incandescent carbon. A vacuum is, perhaps, better, were it not for the difficulty of maintaining it.

The important point is, that the higher the temperature of the incandescent substance, the greater the amount of light; and it is very noteworthy, that it requires nearly half as much current to make platinum shine in the dark as it does to fuse the wire or ribbon. Three quarters of the fusing current will not give one half the light that will be given off by seven eighths of the fusing current. A flat ribbon of platinum will give nearly one hundred candle lights per square inch, if it be maintained within two hundred degrees Fahrenheit of the melting point, and I have been able to keep it at this temperature for hours and days. A bar of pure iridium, owing to its higher melting point, will give several times as much light as an equal and equally exposed surface of platinum; but, since pure iridium is neither malleable nor ductile when cold, it is costly to work it into convenient shape; hence, I have had recourse to alloys of platinum and iridium, which, although they do not give so much light as pure iridium, are yet superior to pure platinum. The platinum does not seem to waste perceptibly, yet I think I have detected a tendency to volatilization.

The resistance of platinum, at the melting point, is nearly seven times its resistance at thirty-two degrees Fahrenheit. A very simple empirical formula expresses the relation between the strength of current needful to melt, and the dimensions of the wire, and this formula serves as well for other substances as for platinum, when the proper constants are supplied.

I found no difficulty in subdividing the current into as many branches as I pleased, and in maintaining as many lamps as I desired in each branch, provided I had, at my control, sufficient electro-motive force and conductivity. I found that less than two hundred foot pounds per minute would maintain one candle light, if the piece of platinum were of suitable form and dimensions. It was easy to supply current to any desirable number of branches, and to so adjust the regulator that, if one, two or three of the branches were removed or cut off, the supply of electricity would be so curtailed as to maintain, at the proper temperature, the lamps in the remaining branches.

My regulator, as I used it in 1866, 1867 and 1868, was so sensitive as to feel the current of air arising from the opening and shutting of a door of the room in which the apparatus was placed.

I had this apparatus on exhibition at 109 Court Street, in Boston, during the years 1865, 1866, 1867 and 1868, until it was destroyed by fire. Since that time I have been almost continuously engaged in making further researches in this direction; have studied the conditions under which incandescent bars of carbon can be used in sealed globes, and have studied the construction of magneto-electric machines best adapted to this purpose.

There are four principal methods of producing electric light, on which I have bestowed much attention:

The first method is that in which an electric arc is maintained between carbon points. It is well known that a counter electromotive force, or polarizing force, is encountered in the passage of the current between the electrodes, and this polarization is often as great in amount as twenty or thirty volts.

The resistance to conductivity in the arc varies also, being less as the cross section of the arc increases, less as the temperature increases, also as the length of the arc diminishes, following the laws of conduction in fluids and liquids. With carbon, one quarter inch square, and a current of from twelve to twenty vebers, the resistance of the arc may be set down at ten to thirteen ohms per linear inch of arc, varying, however, between wide limits.

With carbon one half inch square, and current of fifty or more vebers, it is much less. The best prepared carbon weighs more than an avoirdupois ounce per cubic inch.

The resistance of carbon, unlike that of metals, does not vary greatly with the changes of temperature. The resistance of some specimens, which I have tested, is about fifteen hundred or sixteen hundred times that of pure copper, at thirty-two degrees, while the specific resistance of other specimens is at least twice as great.

The light evolved is due in considerable measure to the oxidation of the carbon by the atmosphere. Much of the light is, however, due to the energy of the current, and this depends on the density of current in the arc.

A second method of producing electric light is by rendering a continuous bar of carbon incandescent in the air by the passage of a current of sufficient density to raise its temperature to a white heat. Here much of the light is due to the superficial oxidation of the carbon bar, and this may perhaps prove to be the most economical method of producing it.

The third method is by enclosing the carbon bar in a closed transparent globe free from oxygen. In this case the carbon is not consumed, but the light is wholly due to the energy (RS^2) of the current acting on the bar.

The fourth method is that of rendering some of the metals, with high melting points, incandescent by the passage of a current of great density.

This is the method to which I have given most attention, and which promises to be the most convenient for minutely subdividing and widely distributing electric light, especially for domestic illumination. An entirely new field for electric engineers is thus opened, in which our accumulated stock of knowledge will be most usefully employed.

Previous to my investigations, Gardiner and Blossom had experimented on and patented a signal lamp, which was illuminated by a coil of platinum wire, heated by the passage of a current of electricity from a galvanic battery.

King, Staite and others had studied the use of carbon bars in sealed globes, and had proposed methods that would have been applicable and useful had there been any cheap and convenient source of electricity. I found that a current from a galvanic battery increased the cost of electric light to three or four times the cost of light from gas; and to remove this source of difficulty I turned my attention to the thermo-electric battery in 1864–5, just then being brought into notice by Marcus, of Berlin. I was, however, never able to utilize more than one three hundredth of the energy possessed by a pound of coal in this form of electro-motor; and so, in 1865–6–7–8, I turned my attention to the perfection of a form of magneto-electric machine which I had conceived of in 1859, namely, one in which the current derived from the armature should maintain the field of force in which it revolved, and also perform the useful work in the external part of the circuit. I succeeded, in 1866, in so far perfecting this apparatus as to be able to give some account of its performance to Mr. H. Wilde, of Manchester, England, in October, 1866, and an extract from my letter to him was published in the Manchester Philosophical Magazine, if I recollect rightly.

From all my researches, I conclude that when light is produced in large amounts—say, five thousand, ten thousand, fifteen thousand candle lights—from one lamp, as much as eight hundred to twelve hundred candle lights can be obtained from the expenditure of one horse power upon a suitable dynamo-electric machine and properly prepared and utilized carbon.

Now, while it is remembered that as much as two thousand or three thousand foot pounds of energy per minute per candle light is consumed in the production of light from ordinary illuminating gas, it will be apparent that a large field is opened for the introduction and utilization of the electric light, which often requires the expenditure of less than one hundred foot pounds of energy per minute per candle light.

A great deal has been said and written about the difficulty of subdividing the electric light. Now, there is really no difficulty except that which arises from inexperience and the lack of skill.

If a wire of pure platinum five inches long and one hundredth of an inch in diameter be traversed by a current of electricity somewhat more than five and less than six vebers in strength, it can be maintained at a temperature quite near to the point of fusion, and while in this condition, it will, in the common atmosphere, emit something more than three candle lights, and just below the melting point the light will be between four and five candle lights.

If the light be enclosed in a glass globe and surrounded by hydrogen gas it will radiate less light. The resistance of the wire at the melting point will not be far from one and a quarter ohms if the platinum be pure; hence the energy active in the wire with a current of five and a half vebers (which it will ordinarily withstand) will not be far from $44\frac{1}{4} \times (5\frac{1}{2})^2 \times 1.25 = 1673$ foot pounds per minute, and if it give four and a half candle lights, which it will do if the surface of the platinum be highly polished, we should require $\frac{1673}{4.5}$=say 370 foot pounds of energy per minute per candle light.

Now, if one hundred such wires be put in series in a circuit, the sum of this resistance would be one hundred and twenty-five ohms, and it would require a difference of potential equal to $125 \times 5\frac{1}{2} = 687\frac{1}{2}$ volts to maintain this strength of current of five and a half vebers and we should get in the aggregate five hundred or more candle lights.

If, further, we should arrange ten such circuits in multiple arc, having one hundred lights in each of the ten branches, we should find the joint resistance of this part of the circuit reduced to twelve and a half ohms; but it would now require a current of fifty-five vebers' strength to keep the lamps all shining, and the difference of potential required to maintain the one thousand lights, each from three to five candles, would still be six hundred and eighty-seven and a half volts; but we should now have five thousand candle lights instead of five hundred, and the energy absorbed in this part of the circuit would be equal to $\frac{44.25 \times 12.5 \times 55^2}{33,000}$ = more than fifty horse power to maintain the five thousand candle lights or one hundred candle lights per horse power. But it must be remembered, that this is not all the energy consumed in the production of the light; this is only the useful energy.

Besides this, there is the R S^2 consumed in heating the leading and distributing wires, also that consumed in the magneto-electric machines or whatever source be employed.

This may be represented by B S^2, wherein B represents the internal resistance of the electro-motor, and can be made as small as one's purse will allow.

On this basis, let us suppose a city of five hundred thousand inhabitants to be furnished with electric light from platinum lamps, one of, say ten candles to each inhabitant. The aggregate amount of light would be five million candles; and if only one hundred candle lights were obtained from one horse power, we should then require fifty thousand horse power to furnish this amount of light, leaving alone the energy consumed in its production and distribution, which would, without doubt, exceed this amount, or nearly so, with the best machine now in use.

If you turn to the account of the experiments on the Brush light, as executed at the Franklin Institute, you will find that the cost of production was, on the average, in excess of one three hundredth of a horse power per candle light; and this, too, with carbon points, and with light in greater amount than ten, fifteen or fifty candle lights per lamp. Now, it is well known that the greater the amount of light at any source, the greater the economy, and so a five or ten thousand candle light costs less per candle than does a ten, fifteen or twenty candle light.

If next we consider the incandescent carbon, in an atmosphere free from oxygen, as in King's, Staite's, Kosloff's, and other lamps of this class, we shall find that a carbon rod three eighths of an inch in length and one thirtieth of an inch in diameter will offer a resistance of not far from half an ohm, whether it be cold or hot, and such a bar will bear a current of from ten to fifty vebers' strength for a time, without injury, and will give a soft, mild and very pleasant light, not too concentrated, but very desirable; and, as with the platinum lamp, many of these lamps can be put in one circuit, and many branch circuits in multiple arc can be heated simultaneously by one source of electricity, provided it have sufficient electro-motive force and conductivity, and the light will be more economical than from platinum, because the carbon, when thus protected, will withstand a higher temperature than will the platinum.

Next, we will consider the electric light produced by the arc between carbon points. If we have two suitable carbon rods, each, say, five sixteenths of an inch diameter, and separated to the distance of about one sixteenth of an inch, and apply to these electrodes a source of electricity, which has an electro-motive force of, say seventy volts, and an internal resistance of, say three ohms, we shall, after establishing the arc, find a current developed of about eight or ten vebers, and a light produced equal to from one hundred to four hundred candle lights.

If the resistance (four ohms) of the circuit were all metallic, the current developed would be in amount equal to sixteen or seventeen vebers; but the electric arc behaves like an electrolyte, and offers a counter electro-motive force, and so the actual electro-motive force in the circuit may be thus represented: $E - e$, where E is the electro-motive force of the machine, and $- e$ the counter or polarizing force of the arc. If, now, l represent the resistance to conductivity of the arc, B the internal resistance of the battery or machine, and r that of the leading wires, then the strength of current active in the circuit will be $C = \frac{E - e}{B + r + l}$

The value of e varies, and all the conditions of its variation are not yet well understood. It is sufficient for our present purpose to know that it is sometimes as high as twenty or thirty volts, and that the resistance to conductivity in the arc is often as high as fifteen or sixteen ohms per lineal inch of arc, being much smaller when the light is very great, say when it is ten or fifteen thousand candles.

With this basis, suppose our magneto-electric machine or galvanic battery possesses an electro-motive force of seventy volts, and an internal resistance of three ohms, it will maintain an arc between carbon points, and, with care, this arc can be made to exceed one sixteenth of an inch in length, if the carbons be of good quality. Now, let us construct a machine with one hundred and forty volts intensity, and with an internal resistance not much greater than three ohms, at least not so great as six ohms. We can now maintain two short arcs in series in this circuit, each giving considerable light. With careful manipulation, even three arcs could be simultaneously maintained with such a machine.

If, now, our electro-motive force were raised to or in excess of seven hundred volts, we might maintain, possibly, as many as ten arcs in one circuit; but the feeding mechanism of the lamps would need to be well constructed, accurately adjusted, and rendered sensitive to slight variations in the strength of the current.

Suppose, further, that our machine has still an electro-motive force of seven hundred volts, but now its internal resistance is reduced to one tenth of an ohm, I doubt not that five or more such circuits of ten lamps each could be run in multiple arcs by the aid of this machine, as it is not probable that all the lamps in one branch would go out at once.

I have maintained three or four branch circuits in action at the same time, each branch having one lamp in it.

I find it much more difficult to run a few lights in each branch circuit than it would be to run several, if the construction of the machine be suitable and the power ample, as the laws governing the strength of current in branch circuits show would happen.

To sum up, then, the electric light question, there are many good and well known magneto-electric machines free to the public to use, for instance, the Saxton, the Siemens, Carpenter, Shepard, and many others; then, too, there is the platinum lamp of Gardiner and Blossom; the incandescent carbon lamps of King, Staite, and others.

Besides these there are the carbon point lamps of Browning, Dubosque, Serrin, Siemens, and many more, which are all free to the public, and hampered by no patents; no carbon point lamp need be better than the Serrin, when properly constructed, as it can be run for hours without flickering, or going out, if the carbons be good, the lamp well made and properly adjusted, and if the machine, which supplies the current, be of ample power.

Light to the amount of from one hundred to one thousand candles per horse power can be obtained from some of these machines and lamps, while at best not more than twenty-five or thirty candle light can be obtained from one horse power's worth of gas.

So let me here repeat what I in substance published in the Scientific American, a few years since, namely, that one pound of coal, if used for making gas, would yield enough to supply a candle light or its equivalent for about fifteen hours.

One pound of the gas, when made and burned, yields a candle light for seventy-five hours. Further, one pound of coal, burned in a good furnace under a good boiler, will furnish sufficient steam to drive a good steam engine, and if a magneto-electric machine, for a sufficient length of time, to furnish an electric light, which in intensity and duration shall be the equivalent of one candle light for one thousand hours.

But if all the energy locked up in one pound of carbon could be liberated and converted wholly into light, it would be equivalent to that given by one candle during one and a half years, if all concentrated in one source.

Hence, let experimenters take courage, and try to fill this chasm between one thousand hours and one and a half years!

When we shall see the electric light distributed in our dwellings it may prove a source of pride to Salem to call to mind that this boon met with its first success in that city, where a parlor, in Pearl Street, was lighted every evening during the month of July, 1859, by the electric light, and was undoubtedly the first private dwelling house ever lighted by electricity.

A galvanic battery furnished the electric current, which was conveyed by conducting wires to the mantel piece of the parlor, where were located two electric lamps. Either lamp could be lighted at pleasure, or both at once, by simply turning a little button.

This light was soft, mild, agreeable to the eye, and more delightful to read or sew by than any light ever seen before. It was discontinued, for the reason that the acids and zinc consumed in the battery made the light cost about four times as much as an equivalent amount of gas light. Now that we can have cheap electricity from the dynamo-electric machine, we may soon expect better things of it.

A word as to the cost of electric light as compared with light from gas. Perhaps on the average, one pound of illuminating gas will give seventy-five candle lights per hour. One pound of illuminating gas possesses a sufficient store of energy to enable it to give out by combustion, about twenty thousand units of heat, or the equivalent of about sixteen million foot pounds of work. This, if burned in an hour, would average about two hundred and fifty thousand units of work per minute, or about thirty-five hundred foot pounds per minute per candle light.

A very large electric light, say ten thousand candles, does not consume more than twenty foot pounds of energy per minute per candle light, and even a small electric light of twenty candles need not consume more than two hundred foot pounds per minute per candle light. So it might not seem extravagant to expect that one pound of gas per hour could be burned in a suitable furnace under a proper boiler, and steam be taken from the boiler to a steam engine to drive a magnetic electric machine, which should supply five electric lamps that would give more light than five gas lamps, each consuming one fifth of a pound of illuminating gas per hour.

CHAPTER III.

THE EDISON INCANDESCENT ELECTRIC LIGHT.

The incandescent system was first represented by lamps made from an incandescent platinum wire, but they did not prove to be satisfactory, principally because of the disaggregation and partial fusion of the wire, and in spite of the numerous improvements made by Mr. Edison, who, by one of the most ingenious of processes, had rendered the platinum more infusible and harder, still it had to be absolutely rejected, at least for ordinary lamps. Then it was suggested to employ carbon, which, if not allowed to burn, is infusible in the highest heat developed in the lamps, and different arrangements of apparatus were put together at various times by King, Lodyguine, Bouliguine, Swan, Sawyer, and others, some avoiding combustion by inclosing the lamps in receptacles where a vacuum had been obtained, others by filling these receptacles with gases unfit for combustion, as nitrogen or oxide of carbon, or simply by leaving the air shut up in the receptacle to be vitiated by an incipient combustion.

All these attempts had but partially succeeded, to say nothing more, when, in 1879, the new incandescent carbon lamp of Mr. Edison was announced, and many scientists at home and abroad were incredulous as to the correctness of the favorable reports which were published in regard to it, amongst whom, in particular, was Count Du Moncel, who has since published a highly appreciative account of the Edison lamp at the Paris Exhibition. The carbonized paper horse-shoe appeared incapable of resisting mechanical shock and of supporting incandescence for any length of time. At this epoch Mr. Swan himself said that up to that time he had not been able to obtain any very satisfactory result by an analogous disposition of the incandescent organ.

Notwithstanding the abundant opportunities for investigation, the impression is still a very general one in the community that the Edison light is an arc light differing in degree only from other arc lights. So far from this being the case, the Edison light is not only not an arc light, but its invention and introduction mark a new and important era in the subject of electric lighting. The Edison light is designed to take the place of the ordinary gas jet to which we have been accustomed for so many years. To give in detail the history of the invention and perfection of the Edison system of lighting would occupy too much time and space, including, as it does, the laborious toil and patient research of many years. Such a history would be exceedingly interesting to the scientist, but it would, perhaps, fail to interest the general reader. We shall, therefore, confine ourselves in this work, more particularly, to a general description of the system, and its constituent parts, and to its practical use.

In discussing the Edison system of electric lighting there are to be considered, first, the dynamo-electric machine; second, the conductors and their accessories; third, the lamps; and fourth, the other constituent parts of the system—all of which are radically different from any others.

THE EDISON GENERATOR.

This machine (Fig. 59) consists of a powerful electro-magnet, between the poles of which an armature, or inducing coil, revolves. The magnet is composed of iron, part of which is wound round with insulated copper wire, the ends of which are connected so as to form a complete circuit. The armature, or inducing coil, is composed of an iron base, this also being wound round lengthwise with insulated copper wire, the ends of which are connected to a smaller cylinder seen in Fig. 59, which is merely part of a mechanical contrivance for collecting the currents generated. The dynamo having been assembled in the shops, it is then started as an electrical machine in the following manner: An ordinary chemical battery is connected with the coils of wire round the magnet, and a current of electricity is sent through such wire, thus charging the iron with magnetism. The armature is then revolved, and its iron base, or core, becomes in turn magnetized. This armature, thus being magnetized, and carrying round with it in its revolutions

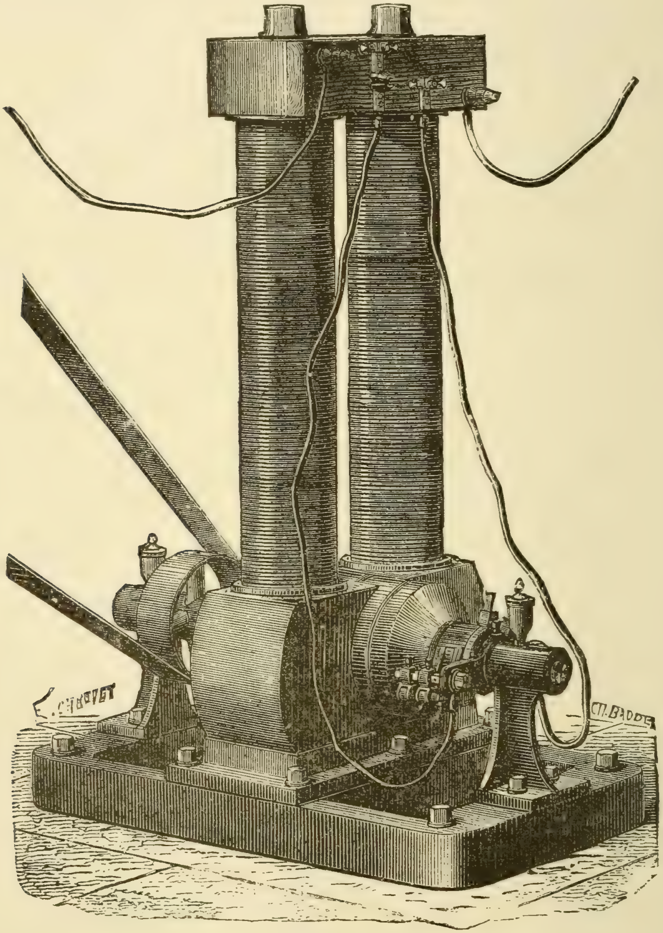


Fig. 59.

the coils of wire with which it is wrapped, induces in such wire currents of electricity. These currents are gathered from the smaller cylinder before referred to by the brushes which form the other part of the mechanical contrivance for gathering the currents. The current then flows through the wire leading from the brushes to the top of the machine, from whence part of the current so generated is shunted back through the coils of the magnet, thus increasing its magnetic strength, the surplus being distributed through the conductors and appearing at the points desired in the form of light. The magnet being now charged, any further use of the chemical battery is unnecessary, inasmuch as a small portion of magnetism always remains in the magnet. This residual magnetism is very weak, but it is sufficient when the armature is caused to revolve, to again extend its influence thereto and to again induce currents of electricity, part of which is being constantly shunted through the coils of the magnet, and increasing its strength as long as the armature continues in motion.

This is the theory of all generators of electricity, except that in some other dynamos the magnetizing of the magnet is produced by a current of electricity from an entirely distinct generator of smaller size, called an exciter.

Of the peculiarities and improvements presented in the Edison machine, we may mention two, which are regarded as of a fundamental character and of the greatest value in the economic production and distribution of electric currents for light or power. These improvements are, first, the principle of maximum external work, that is to say, the maximum production of current which may be availed of for sale to and consumption by the customer. Second, the principle of economy in the production of electricity.

When Mr. Edison took up the subject of electric generators, an idea prevailed in the minds of previous inventors that generators should be based on the principle of maximum current, and that the external resistance to the passage of the current should equal the resistance in the machine itself.

It may be well to explain briefly the meaning of these technical terms, external resistance and internal resistance. Electricity in motion may be regarded as a current which in its course through a conductor follows the same natural laws as water. If we force a large quantity of water through a narrow pipe, there will be offered to the passage of the body of water more resistance than if the pipe were larger. So it is with an electric current, the resistance to the passage of which is inversely proportional to the size of the conductor. External resistance means that of the circuit outside of the generator, or, in other words, the circuit upon which the current is being used in the form of light. Internal resistance means that which is offered to the circulation of the current within the various portions of the dynamo itself.

The resistance of the large copper conductors forming a portion of the external circuit, in the Edison system, is of itself a small item, but when a lamp is placed between the two copper conductors, and is thus made a part of the circuit, the resistance of the external circuit becomes 140 ohms.[1] It may seem contradictory to those unacquainted with Mr. Edison's system, when we state that every additional lamp decreases the total resistance placed in the external circuit; but when we consider that every lamp offers an additional passage for the electric current, the reason for this decrease of resistance becomes very plain. Arguing from these facts and from another one, namely, the fact that the resistance of the external circuit must never be less than that of the internal circuit, it will be readily seen that in the dynamos of other inventors a limit to the number of lamps which can be used in the external circuit is quickly reached, because in such machines the internal resistance must be equal to that of the external circuit, while in the Edison machine the resistance of the internal circuit is almost infinitesimal, and for this reason a great number of lamps may be added before the resistance of the external circuit is brought down too low. Now, the value of a generator is obviously the amount of work which can be obtained from it in the external circuit, that is to say, in the form of light; the work in the machine itself being not only unavailable, but injurious, since it heats the coils of the machine. It will, therefore, be seen that in the exact proportion in which the internal resistance is kept below the external resistance is the useful efficiency of the machine. This is what Mr. Edison has accomplished by making the internal resistance of his machine exceedingly low; in fact, so low as to be, in this respect, practically perfect.

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[1] The unit measure, which was officially adopted at the Paris Electrical Congress in October, 1881, was as follows:

The elementary unit, or unit of resistance, is the ohm, which equals, very nearly, a column of mercury or wire of mercury, one metre in length, and one millimetre in sectional area.

The unit of potential, or electro-motive force is the volt, which is practically that of a Daniell's cell.

The ampère is the amount of the electricity, or the current, flowing through an ohm, impelled by the electro-motive force of one volt; it was formerly known as the Weber.

The coulomb is the current that would flow in an ampère in one second.

In regard to the second improvement just spoken of, there is also seen for the first time in the history of this subject high electro-motive force combined with extremely low resistance. This feature is also one of the radical differences between the Edison and other types of generators. In other generators heretofore made, the effort has been to produce the maximum of current with the smallest weight of iron and copper in their construction, not to produce the maximum of current from the minimum of mechanical energy expended. The electro motive force is proportional to the strength of the field, and a field of a given strength may be produced in two ways: first, by using iron cores of small size and by magnetizing them strongly by a very intense current; or, second, by using larger magnet cores and magnetizing them by a less intense current. In the former case the magnetic field is obtained by the expenditure of current, which also means expenditure of horse power; in the latter by the expenditure of iron. The one is the more economical than the other according as the cost of current or of iron is the greater. Hitherto the effort seems to have been to make the field magnets as small and short as possible, and to send through them the entire current produced by the machine. In the laboratory the absolute cost of one ampère of electrical energy is a secondary consideration, the whole question being the relative cost as between similar machines. But in practice the absolute cost of the electricity is the fundamental question upon which commercial success mainly depends. Mr. Edison, therefore, made the inquiry whether it is cheaper to produce the required magnetism by using small magnets charged by powerful currents or large magnets charged by weaker currents. Since current is expended in the field, and must be continually reproduced, while the expense for the iron is only the interest on the first cost, it would appear that the latter course was the cheaper one. But it is found that the amount of electricity necessary to magnetize iron rises in a very rapid ratio as the point of saturation is approached, it requiring, when the iron is half saturated, about one hundred times more current to fully saturate it. Practically, therefore, given the strength of the field, the question is which is more economical: to expend more current and use less iron, or to use a weaker current and more iron; the cost of the iron, the cost of the current, and the percentage of saturation by a current of given strength, affording the data for the computation. It is found an ampère can be produced for less money by using large magnets and a current sufficient to half saturate them. This idea is carried out in the Edison dynamo, in which large magnets, half saturated, are used.

There is also one other improvement in the Edison dynamo which enters into the point of economy. It is in the construction of the iron base of the armature. At the time when Mr. Edison was working on this subject, armatures of the cylinder type were made with solid iron bases, the revolution of which caused the production of heat in the body of the armature, and, second, considerably lessened the efficiency of the machine.

Various devices were adopted to remove this heating, such as blowing a current of air or passing a stream of cold water in the neighborhood of the armature to reduce the heat. But, as we all know, heat developed means energy wasted, and Mr. Edison characterized his dynamo by a fundamental improvement in this direction. He undertook to ascertain what was the cause of the heating of the body of such armatures. He revolved a block of iron between the poles of an electro magnet, and, after running the same five minutes, it was found that a piece of meat laid upon it could be well cooked by the heat developed. He, therefore, found it would be necessary to break up the inducing currents and so do away with this injurious heating of the armature. Accordingly, then, he constructs his armature of disks of thin iron separated from each other by a sheet of tissue paper, thus breaking up the induced currents and the injurious heating.

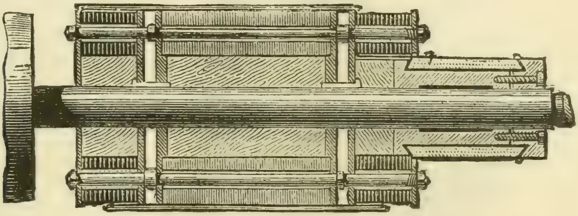


Fig. 60.

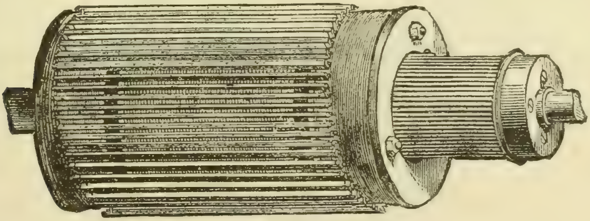


Fig. 61.

The armature wire consists of bars of copper. These bars lie close to each other around the cylinder which forms the

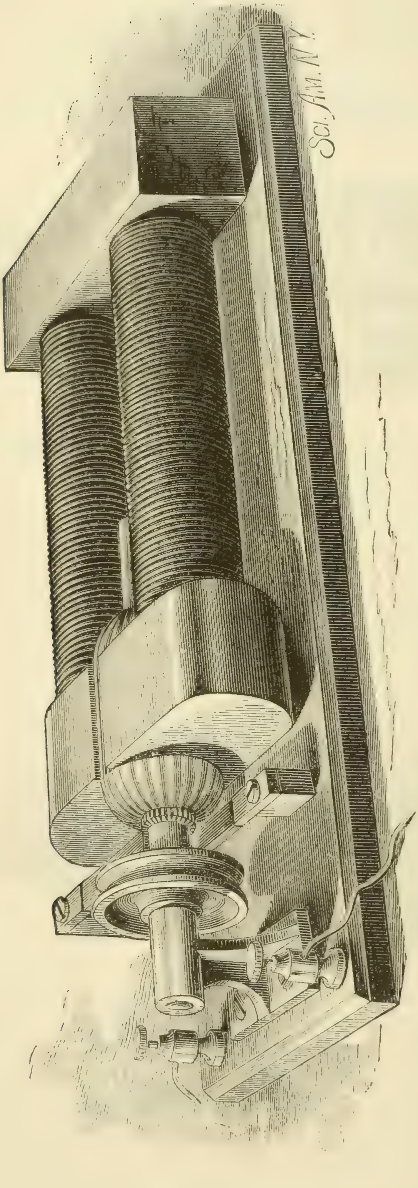


Fig. 62.

armature, and generate the current. Their extremities correspond to disks of copper (at right angles to them) laid one against the other at the ends of the cylinder and insulated from each other. Each bar is attached to these disks in such a way as to form a single circuit, enveloping the cylinder longitudinally, and which is itself connected through the coupled bars, with the collector. Figs. 60 and 61 give an idea of this new arrangement. The centre of the cylinder itself is occupied, outside of the rotating axle, by a cylinder of wood, which in its turn is surrounded by a thick tube made of a series of very thin disks of iron, separated from each other by paper.

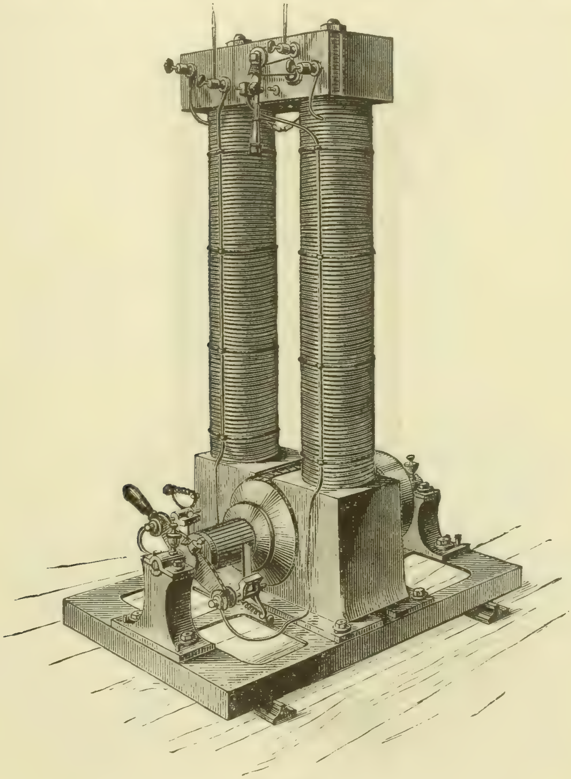


Fig. 63.

This arrangement facilitates the rapid changes of polarity in the plates. This tube is terminated at its two extremities by two thick clamping disks which are made to compress the others laterally, and the copper disks of the working coil occupy the two compartments at the extremities of the cylinder, as seen in Fig. 60. Under such conditions as these, the resistance of the generator is small, and permits of great subdivision of the current in multiple arc; nor is there any insulation to be burned; and in case of the deterioration of the bars, they can be easily renewed, for they are simply screwed against

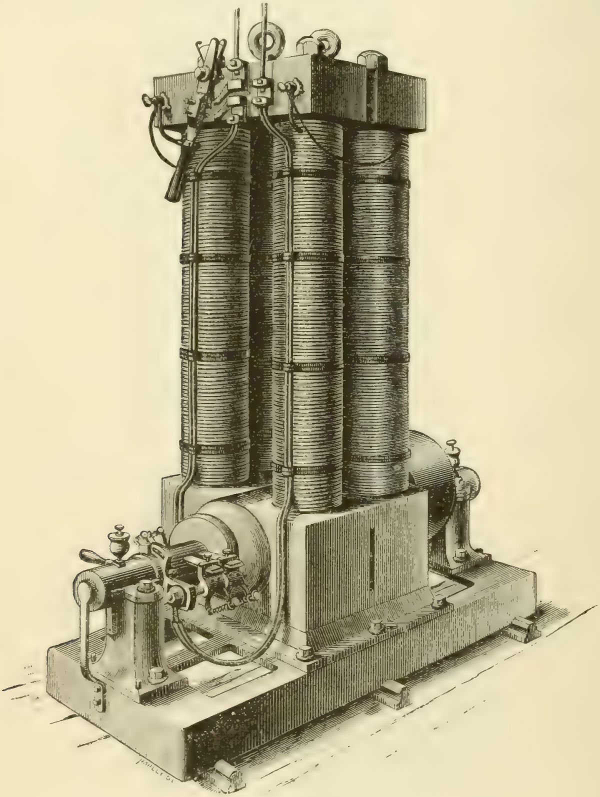


Fig. 64.

the copper disks corresponding to them. In the large machines now made by Mr. Edison, the field magnets lie horizontal (fig. 62), instead of being placed in the vertical.

The Edison dynamos are at present made in five different sizes, for supplying 15, 60 (fig. 63), 150 (fig. 64), 250 (fig. 65), and 1,200 sixteen candle power lights respectively: or double this number of eight candle lights. The power usually estimated for these machines is 4, 10, 18, 34, and 150 horse power, for the

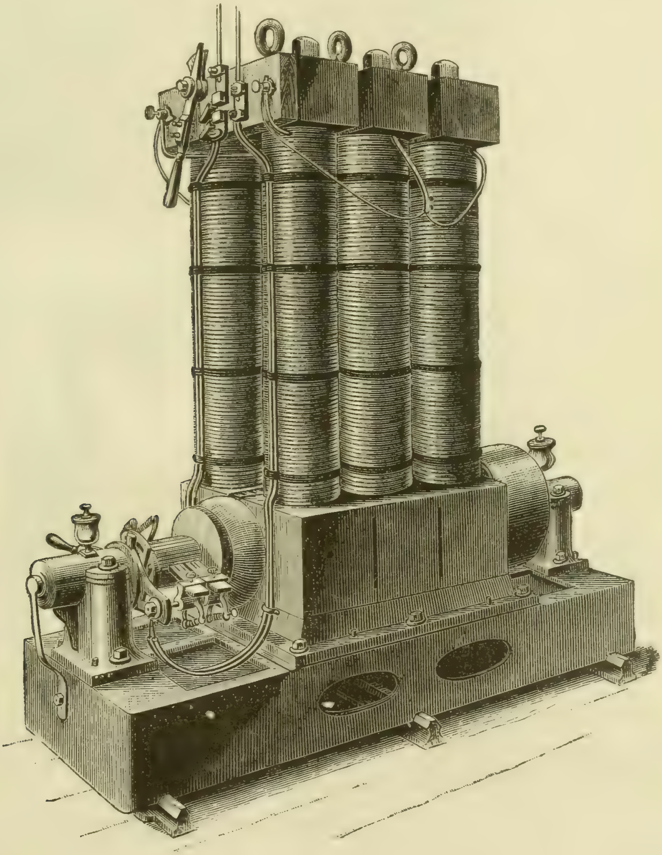


Fig. 65.

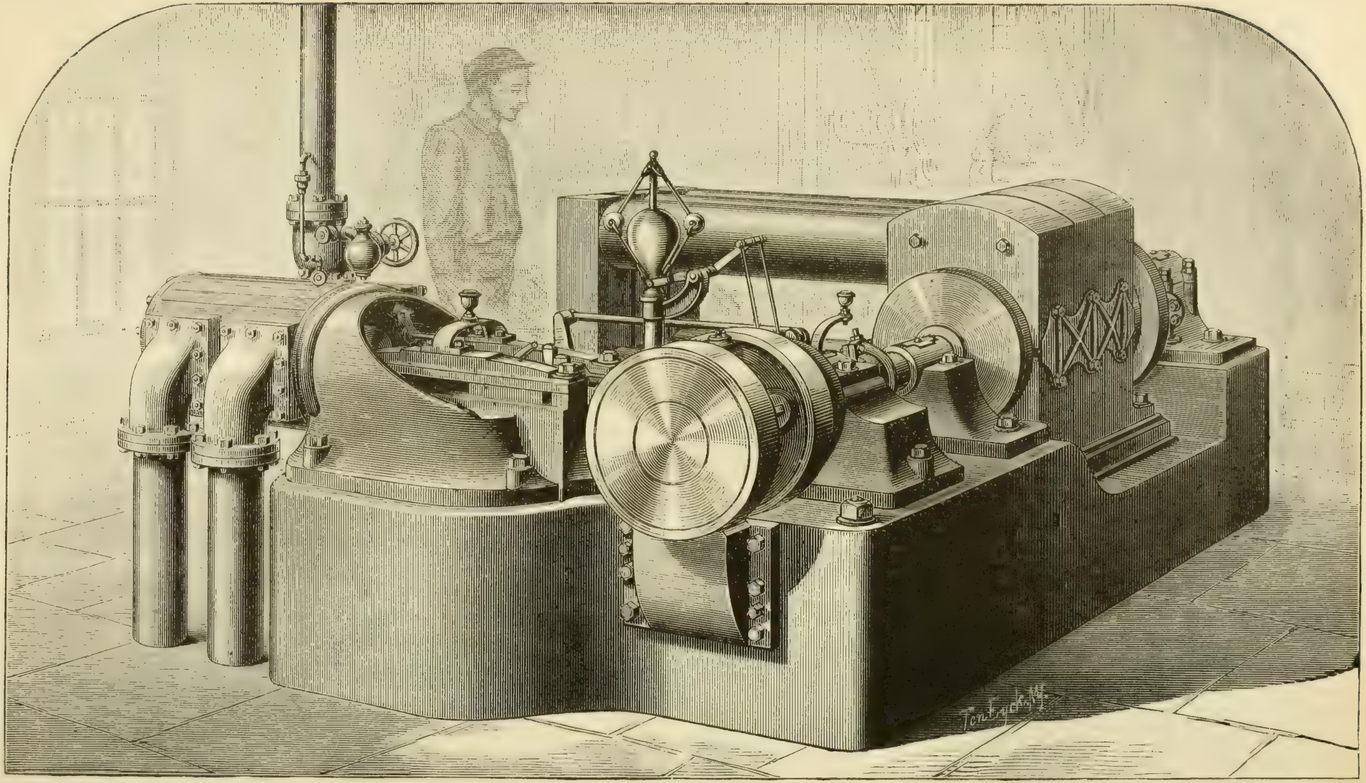


Fig. 66.

five machines. This is a liberal estimate of power, Mr. Edison not desiring to be understood as limiting the light producing capacity of the machines to the precise number of lights above stated where such horse power is used.

The Edison generators for 1,200 lights and above are constructed on a modified plan. The first of these giant machines was exhibited at the Paris Electrical Exhibition, where it furnished the current for 500 lamps in the grand staircase, 250 lamps in the Edison exhibit rooms and about 200 more scattered over the building.

This machine (fig. 66), with its engine, rested on a cast iron bed plate 12½ by 8½ feet, weighing 9,600 lbs. The field consisted of eight electro-magnets each 8 feet long, placed horizontally and weighing 24,500 lbs. The armature was 28 inches in diameter and 5 feet long, and weighed with its shaft 8,500 lbs. In place of wire, copper bars three quarter inches in diameter (fig. 67), covered its surface parallel to the axes, their ends being connected with flat disks of copper, insulated from each other, which served to convey the current across the ends of the cylinder. Figs. 68 and 69 show the copper disk, and

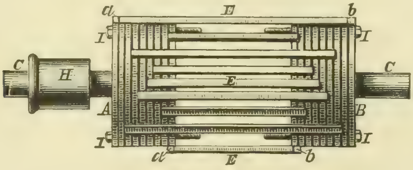


Fig. 67.

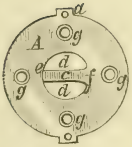


Fig. 68.

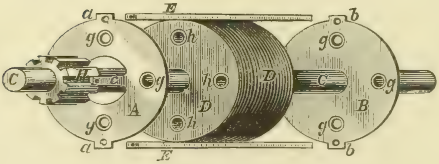


Fig. 69.

large armature. The object of the bar armature is to furnish means for easily removing and replacing one or more coils of the armature. For the generative portions of the armature. coils of wire or naked bars are employed, electrical connections from each bar on the opposite side of the armature being made through disks. If each longitudinal set of wires, or each bar, be considered as one coil, a series of disks equal in number to half the coils is used at each end of the armature. Referring to the illustrations, which are diagrammatic in their character, A (fig. 69) represents a disk at the commutator end of the armature, and B a disk at the other end.

Each disk, A, has a hole punched out of the centre, and a finger, *c*, bent out at right angles to the commutator block, H. D is a core of insulated disks of soft iron. Supposing the upper bar, E, to be moving through the polar space of the magnetic field, a current would traverse it, say, from left to right, enter the disk 2, by the lug, *b* (fig. 67), cross the disk, and return by a bar not shown, but immediately behind the lowest bar, E, to the disk 3, and then two paths would be open to it, one by the tongue, *c*, to the commutator, and the other through the second bar, E, attached to the disk 3. The same would occur in each pair of bars and disks.

The resistance of the armature was only 0.008 ohm. The commutator was nine inches long, composed of heavy bars of copper. The engine weighed 10,000 lbs. and had a cylinder 11 by 16 inches. With a boiler pressure of 120 lbs. and 350 revolutions per minute, it developed 150 effective horse power. The total weight of the machine was 44,600 lbs., and the weight of copper on the magnets and armature was 3,600 lbs. Subsequently, twenty-seven other machines have been made upon the same plan, but larger, their total weight being 36 tons each. The tests of these machines gave excellent results, showing the production of 7.44 16-candle lights per indicated horse power. Two of these machines were sent to London, and are now working at the Holborn Viaduct Station.

The Edison dynamo is able to convert into electricity the mechanical energy derived from the steam engine with a loss of only five per cent.

A distinction is, however, to be made here between total efficiency and commercial efficiency. The former is the ratio of current energy produced to mechanical energy absorbed, and is the efficiency ordinarily spoken of, of machines. But, as shown above, the useful work of a machine is that done in the external circuit. Hence the commercial efficiency, or, in other words, the economy of the machine is its total efficiency multiplied by the ratio of the resistance of the external circuit to the total resistance. If the total efficiency of these dynamos is 95 per cent., and the ratio above mentioned be $\frac{40}{41}$, the commercial efficiency will be $95 \times \frac{40}{41} = 93$ per cent. These results have been established by the tests made by Professors Brackett and Young upon the earlier dynamos made by Mr. Edison, which showed 89.9 per cent. total and 84.1 per cent. of available efficiency. (Am. J. Sci., III., xix. 475, June 18, '80), and by Mr. Howell, of the Stevens Institute, upon the later and improved apparatus, which showed 95.10 per cent. total, and 88.7 per cent. commercial efficiency.

The smaller dynamos only are used for isolated lighting, the larger for general illumination. They are not liable to get out of order, and need no more than five minutes' attention each day for oiling and changing position of the brushes. They may be run by any ordinary engineer after a few hours' instruction by the company's men, who are sent to erect the machine. A special engineer or electrician is, therefore, entirely unnecessary.

The current generated by the Edison dynamos is absolutely harmless to life or health. The wires at any part of the system, even the pole-pieces of the machine itself, may be grasped by the bare hand firmly or otherwise, without the slightest injury whatever to the person. In fact, so low is the electro motive force or tension of the current that it can scarcely be felt at all.

The following is a description of Mr. Edison's Radial Bar and Disk Dynamo Electric Machine, patented August 22, 1882 :

Mr. Edison's object in this invention was to produce a dynamo or magneto electric machine in which the iron core of the armature would not be necessary, and the loss of power caused by heating would be avoided, the inductive portion only of the armature being passed between the poles of the exciting magnet or magnets, which poles can consequently be brought close together, so as to produce an intense magnetic field, and which will generate a continuous current of high electro motive force in the same direction without the use of pole-changers. All the inductive portions of the armature are constantly in circuit, and the internal resistance of the machine is exceedingly small.

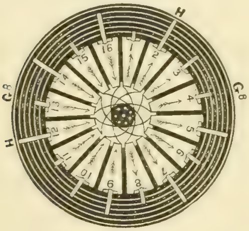


Fig. 70.

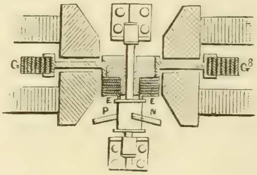


Fig. 71.

Mr. Edison accomplishes this object by constructing the armature in the shape of a disk or plate like that used by Arago in his experiments, but divided into radial sections. These radial sections, which form the inductive portion of the armature, are naked copper bars connected together by insulating material, and attached rigidly to the driving-shaft by an insulating-hub. At their inner ends these bars are connected in pairs, by means of metal plates insulated from each other, which plates have tongues secured in the grooves of an insulating commutator-cylinder. The radial bars revolve between the polar extensions of two magnets, and outside of their polar extensions the disk formed of radial bars and insulating material is surrounded by concentric metal rings, which are insulated from each other and the radial bars, except as hereinafter explained. The number of the rings is one half that of the radial bars. The pairs of bars are connected in multiple arc at their outer ends by these concentric rings, by means of bands, or rods extending from the bars to the rings, and being insulated from all the rings except the ones they are intended to connect with the bars. The rings connect the bars in such manner that the connections are symmetrical at every position of the machine. The rings are complete, and extend in both directions from and to the connecting bands or rods, so that the plates are connected in multiple arc, half the current passing in each direction. The current, commencing at the negative commutator brush, is divided into two parts, each of which parts passes through one half of the radial bars and combines with the other part at the positive commutator brush. In this manner all the bars are continually kept in circuit, and a current is generated having an electro-motive force due to one half the length of all the plates. The concentric rings are arranged outside of the polar extensions, so that these extensions can be brought close up to the inductive bars, while the rings are nearly outside of the magnetic field, and do not cut the lines of force at right angles, and consequently have no counter effect upon the electro-motive force of the current. As the plates connecting the radial bars with the commutator, the concentric rings, the connecting bands, or rods, and the radial

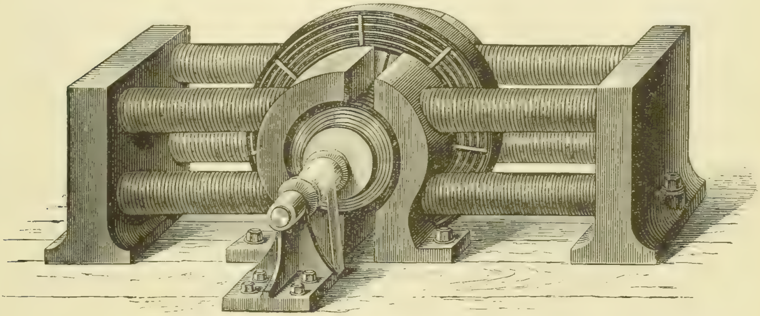


Fig. 72.

bars themselves, all have large conducting area, the internal resistance of the machine is exceedingly small.

The novel features of this machine are also applicable to electric engines and motors. As an engine or motor the construction would have the advantage of great lateral compactness, enabling its use on a narrow railway-car without projecting over the sides of the car, or in other locations where space is limited.

Figure 70 shows the revolving armature with the commutator in section, the connections of the radial bars with the commutator being shown diagrammatically; Fig. 71 a central horizontal section of the machine, and Fig. 72 a perspective view of it.

The radial naked copper bars, which are numbered 1 to 16, inclusive, are mounted upon a hub, secured to the shaft and properly insulated from such shaft. These bars are joined edgewise by a non-conducting material, so that they form a rigid disk or plate. The radial bars are turned outwardly at their lower ends and connected thereby, or by rods, with plates, E, which are insulated from each other and have tongues, two of which are shown in Fig. 71 extending outwardly and forming the conducting portions of the commutator-cylinder.

Two radial bars are connected with each plate, E, and by it connected with the nearest central commutation-bar. In the arrangement shown, the pairs 1 and 8, 2 and 11, 3 and 10, 4 and 13, 5 and 12, 6 and 15, 7 and 14, 9 and 16 are connected together and to central commutator-bars. The concentric rings, G^8, surround the disk formed by the radial bars, outside of the polar extensions, and are insulated from them. The radial bars are connected in couples by the rings by means of the bands or rods H. The neutral line extends vertically through the centre of the armature, while the commutator brushes or springs P N make contact with the sides of the commutator-cylinder at the ends of its horizontal diameter, the bars next to the neutral line being connected with the central side commutator-bars, as shown and previously explained. On the left-hand side of the neutral line the currents in the radial bars, as shown in Fig. 70, all run inwardly, while those on the right-hand side flow outwardly. In the position shown one portion of the current would pass from the negative to the positive commutator-brush, *via* 1, 11, 2, 12, 5, 14, 7 and 16, and the other portion *via* 8, 15, 6, 13, 14, 10, 3, and 9, the proper plates E and straps H being included in the circuits.

By dividing the disk into radial sections or bars and connecting them, so as to generate a continuous current, a much higher electro-motive force can be obtained than by the use of the simple undivided disk employed by Arago in his experiments.

THE EDISON CONDUCTORS.

The conductors used in the Edison system are of two kinds: First, the mains which are used to distribute the current from the central station through the streets; and second, the wires, which are used within the houses to be lighted. The former conductors are semi-cylindrical rods of copper placed in iron pipes. Every six or eight inches they are supported in these pipes by blocks of wood, and the pipe is then filled with an insulating composition. This complete conductor is made in lengths of 20 feet. It is laid under the ground, eighteen inches or so outside of the curb on each side of the street, and twenty-eight inches beneath the surface. The tubes screw into a cast iron box, within which contact is made with a lateral branch, which is carried within the curbstone and there capped. Every 20 feet, therefore, the main conductor is tapped, and the house conductors can readily be reached by taking up a few bricks or a flag on the walk without disturbing the street paving. Fig. 73 shows one of these boxes with its connections.

Within the house, the conductors are of copper wire, unless the number of lamps is so great as to require very large conductors, in which case conductors enclosed in iron pipes are used, but of smaller size than the mains. The wiring of buildings for the Edison light is done by skilled workmen employed by the company. The wires are placed two and a half inches apart, each wire having a double insulated non-combustible covering and being further protected by a wooden moulding containing grooves on the under side to receive the wires, thus rendering any contact or crosses between them almost impossible.

Figure 74 represents the moulding with a piece cut away on the left side to expose the wire.

In case any accidental contact between the wires should happen, caused either directly or indirectly by the contact of any metallic conductor, such as a gas or water pipe, with them, Mr. Edison has invented a device termed a safety catch, which secures absolute freedom from danger by fire, and is an essential feature of his system of distribution. In the system of electric distribution this device is intended to play a part analogous to that performed by the safety valve in a steam boiler or an overflow pipe in a system of water supply. It consists simply of a short piece of wire, fusible at a comparatively low temperature, which is inserted in and forms part of every circuit. The wire is an alloy of lead and tin, and is contained in an adjustable plug or block. The object of the safety-catch is to obviate the danger of fire arising from an excess of current at any given point. For instance, if from any cause an excessive amount of current passes through the circuit, the safety catch would immediately fuse, and thus cut off the flow of the

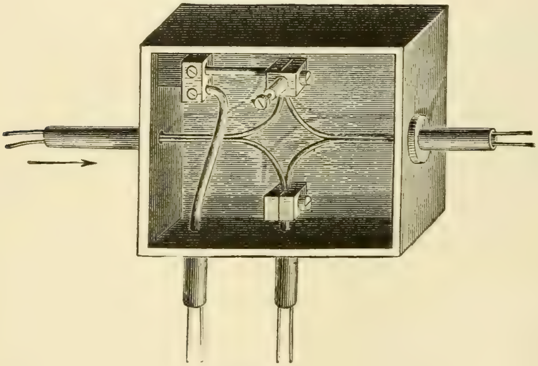


Fig. 73.

current before any danger could possibly be done by overheating the wires. To make this perfectly clear to those who are unacquainted with electrical science, it should be stated that in the Edison system the current of electricity running through the wires is always of a given tension or pressure, and that the Edison lamp has a resistance exactly proportioned to this tension. It is a well known fact that when two or more paths are open for the passage of an electric current, it will follow each in proportion to the facilities offered, and that the greater portion of it will take the easiest way; and, therefore, if two conductors are placed across the two copper rods forming a part of

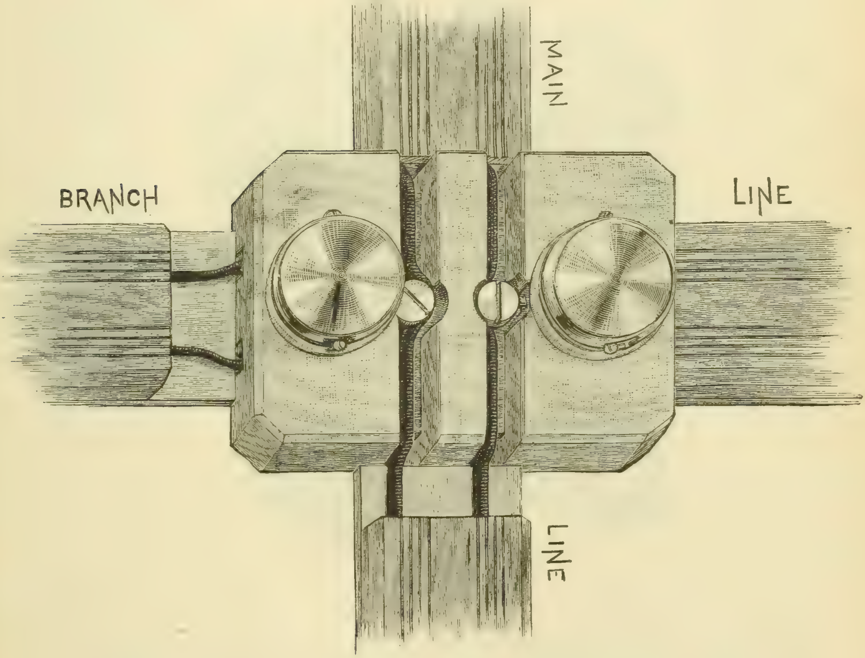


Fig. 74.

the circuit in the Edison system, one having low and the other high resistance, the bulk of the current will pass through the one having the smaller resistance. Now, if by any accident one of the wires conveying the current to the lamps were to come in contact with the other wire, or if some other metallic body, such as a gas or water pipe, should come in contact with both of the conducting rods, there would be a conductor of considerably less resistance inserted in the circuit, and the current would immediately rush to that point, because it would afford a much easier passage. The consequence would be the fusing of the copper wires, and, possibly, the setting fire to the adjacent woodwork or other inflammable material. It is to obviate this danger that the safety catch or weak point is interposed in every circuit. In the case of a rush of current as above described, the effect would be to immediately fuse the safety catch and effectually interrupt the flow of the current. When it is

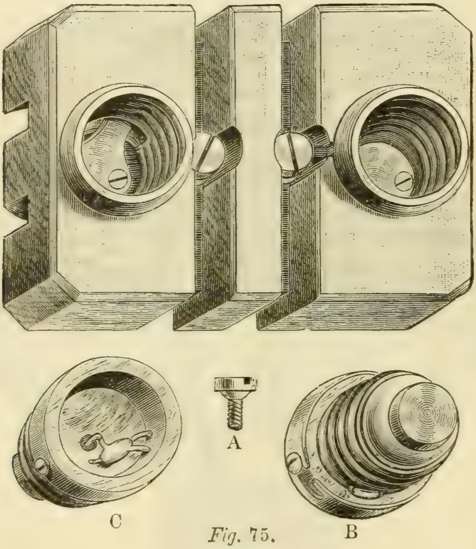
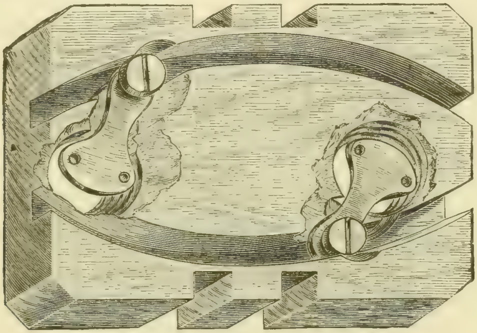


Fig. 75.

stated that the fusing point of the safety catch is between 450 and 500 degrees Fahrenheit, and that of copper wire 2,143, it is at once apparent that when the copper conducting wires are yet comparatively cool, the safety catch will melt. In fact, by the use of this device, fires are practically impossible in the Edison system. The safety catch wire is usually inclosed in a small receptacle called the safety catch plug, and should the wire fuse, the current may be restored by merely taking out the old plug and inserting a new one—the work of a moment.



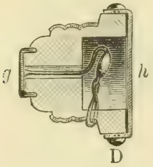


Fig. 76.

Figures 75 and 76 are front and back views of the double cut out, or safety catch. It is composed of a block of hard wood, with grooves cut in it for the main and branch wires to pass through, and having two large holes bored through it, in each of which is inserted a short brass thimble upon the inner surface of which screw threads are cut. These brass thimbles are attached to the main conductors by set screws (A, fig. 75), running into the grooves through which they pass. One of the brass thimbles is thus connected with the incoming and the other with the outgoing wire. At the bottom of each of the holes in figure 75 is seen a portion of a brass plate with a screw head appearing above it. This plate is fastened to the wooden block so as to lie, at one end, under the hole, and the other end is connected by a set screw with the branch wire. This plate is insulated from the thimble. The arrangement of the little brass plate can be seen more clearly in the back view of the double cut shown in figure 76.

One end of the plate is seen to cover the bottom of the thimble, or screw hole, while the other end is connected by a binding screw to the branch wire running through the curved groove. Now, as the main wires are connected with the brass thimbles, and the branch wires are connected with the brass plates under the thimbles, it is evident that the main and branch wires would be connected if the thimbles and plates were united. This union is made by means of plugs, one of which is shown in section in D, figure 76. This plug is made of a non-conducting material in the form of a thumb screw, to fit into the brass thimble. The upper part of the screw, *h*, is covered with brass, which when it is in place, is in metallic

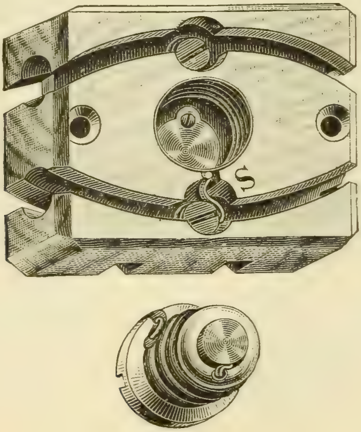


Fig. 77.

connection with the main wire through the thimble, and it has a brass cap, *g*, at the bottom, which connects with the branch wires through the metallic plate under the screw hole, and the top and bottom plates of the plug are connected by means of a wire of lead and tin alloy, contained in the interior of the plug, as shown in the sectional cut E. B, figure 75, shows one of these plugs removed from the block and turned upside down. C, figure 75, shows one right side up, while figure 74 shows the two plugs properly inserted in the block. The upper ends of the plugs are protected by brass caps, which can be removed, for the purpose of examining the condition of the fusible wire, without removing the plug or disturbing any of the connections.

Figure 77 represents a single cut out, which is employed in all cases where it is not considered necessary to introduce the cut out upon both the incoming and outgoing wire. This cut out is precisely like the other, except that it has but one safety plug, which is introduced in one of the branch line wires. The single cut out is apparently sufficient for safety, but Mr. Edison uses two in order to insure double security.

THE EDISON ELECTRIC METER.

Where the consumer of electric light generates his electricity as well as uses it, as in the case of a separate plant for lighting a factory, the question of cost is one of generation only. But where the electricity is produced at and distributed from a central station in a manner similar to the production and distribution of gas, it is obviously necessary to have some means of knowing accurately the amount of electricity which is supplied to the customer. It would seem at first thought quite impossible to measure so intangible an agent as electricity. But Mr. Edison has succeeded in devising a form of meter which enables the quantity of electricity consumed in a house to be as easily ascertained as the quantity of gas, and far more accurately. In the Edison meter advantage is taken of the fact that when an electrical current is passed through a solution of a salt capable of decomposition, it is decomposed in quantity exactly proportional to the strength of the current. If a current be passed through a solution of zinc, for example, for every ampère of current which passes, 0.334 milligram of zinc is decomposed per second. Since this zinc is deposited on the negative plate, it is evident that by weighing this plate at the beginning of the month when it is inserted in the meter, and again at the end of the month when it is taken out, it would be easy to calculate the number of ampères current which had passed during that time, and inasmuch as the number of candles' light which this ampère will give is definitely known, a computation of the amount of light supplied to the customer is easily ascertained. To maintain 100 sixteen candle lamps for a month, however, a current would be required which would deposit in that time between 130 and 140 pounds of zinc—a quantity too large for practical purposes.

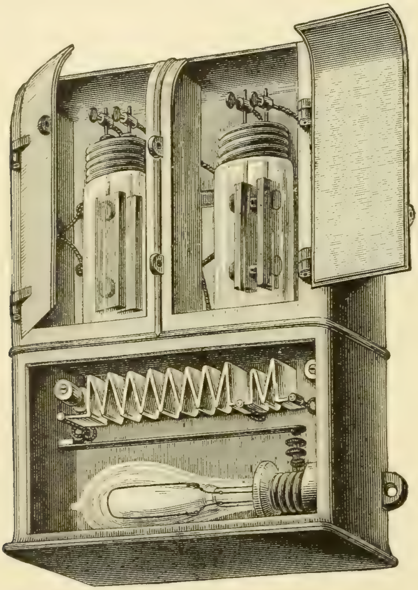


Fig. 78.

The meter is, therefore, placed in a collateral or shunt circuit, whose resistance is made exactly one thousand times greater than that of the main circuit. Hence, one thousandth of the main current only goes through it, and, of course, one thousandth of the zinc is deposited. By multiplying the current equivalent to the zinc deposited by the ratio of the shunt, the value of the whole current is obtained.

Figure 78 shows the meter and figure 79 the arrangement of the main and branch lines with the meter in circuit.

The meter consists of a jar containing the zinc solution in which two zinc plates are suspended from the cover, one attached to the incoming and the other to the outgoing wire. The whole is inclosed in a neat box of cast iron. A second similar jar is also placed in the box, through which a tenth only of the shunt current is allowed to pass—that is to say $\frac{1}{10,000}$ of the whole current. This is intended as a check to the other jar in case of doubt arising as to the correctness of its indication from any cause, as the shifting of plates, etc. To each jar a coil of wire is attached for adjusting the resistance of the branch circuit. An extremely ingenious device is attached to this coil. It is well known that the resistance of solutions decreases with the rise of temperature, while that of metals increases. A corrugated strip of metal forms part of the voltameter circuit, so proportioned that its change of resistance by a variation of temperature is equal to and opposite to that of the liquid. The resistance of the meter is thus preserved constant and independent of temperature, thus always assuring correct measurement.

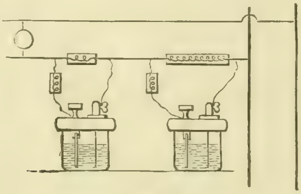


Fig. 79.

There is one more ingenious contrivance in the Edison meter designed to prevent the inconvenience occasioned by a frozen gas meter. In cases where the meter is likely to be exposed to a temperature at which the liquid would freeze, an ordinary Edison lamp is placed within the meter case and a compound strip of iron and brass is so arranged that when the temperature falls to 32 degrees of Fahrenheit, the strip, by the differential contraction, becomes contracted so as to close a platinum contact and light the lamp. As soon as the temperature has risen sufficiently the contact is automatically broken and the light is extinguished. These phenomena are repeated as often as the change in temperature takes place.

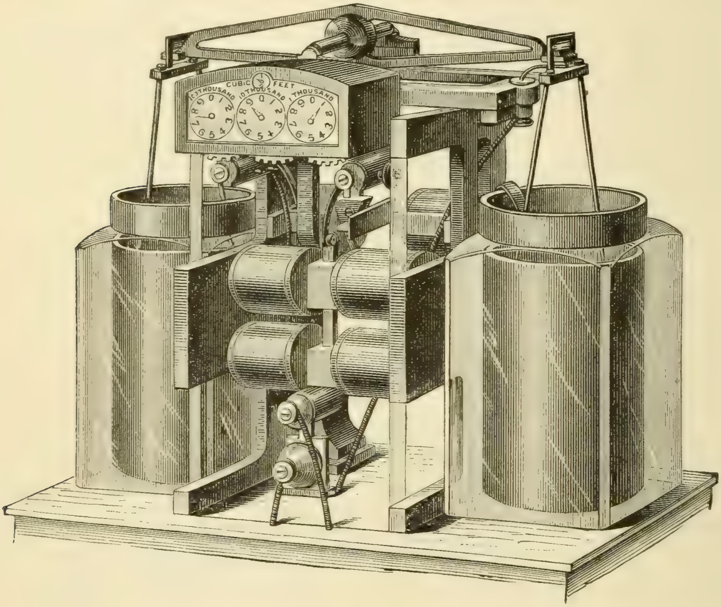


Fig. 80.

Another form of meter (fig. 80) has been devised by Mr. Edison, which he has called an ampère meter. Like the one just described, it depends on the principle of electrolysis by the current. A carefully poised balance beam supports at its ends two copper plates, which are immersed each in its own jar of solution. Since the current passes in the inverse direction through these jars, the copper is dissolved from one plate and is deposited on the other, thus causing the beam to turn. Attached to this beam is a commutator, so that, when it reaches a certain angle, the commutator is moved and the current reversed. The copper is now removed from the plate on which it was deposited before and deposited on the other plate. And thus a permanent oscillation of the beam is produced. By a train of wheel work, the number of oscillations is recorded: and by suitably proportioning the parts of the apparatus, the identical counter is used which is used in the gas meter; so that it registers cubic feet of electricity, a cubic foot of electricity being the quantity required under the conditions of the Edison system to give the same light as a cubic foot of gas.

This form of apparatus may be used for measuring extremely minute currents. In one form of it, exhibited at Paris, the whole apparatus is exceedingly delicate, and the motion of the beam is multiplied by that of a mirror attached to it, by which a beam of light is deflected. So sensitive is this instrument that it is capable of indicating in one minute a current so feeble that it would require a century to deposit an ounce of copper.

THE EDISON FIXTURES.

The simplest fixture is the conducting wire itself, upon which the lamp, by means of its wires, may be hung. But for permanent installation some devices must be contrived for solidly supporting the lamp, for concealing and protecting the conductors, for turning the current on and off, and for connecting several lamps in a single group. It was at first proposed to use gas fixtures, the gas pipe serving for the return current. But several objections developed to this course—first, owing to imperfect joints, the resistance of the gas pipes in ordinary houses is so high that economy of current repays the cost of a return wire; second, there would be some risk of fire in using ground; and third, if the fixtures constituted a part of the circuit, a slight tingling sensation might be perceived, under certain circumstances, on touching them. This latter, although trifling, would cause distrust and prejudice on the part of servants and others not informed. Hence Mr. Edison early determined to put in double wires throughout; and his competitors, who used gas pipes as return circuits, are now following his example. His views have been adopted by the fire underwriters, who have made stringent rules declaring against the use of ground circuits in electric lighting.

The lamp is furnished with a plaster cap having a brass ring and tip, each connected with one of the wires fastened to the carbon. The ring has a screw thread upon it which enters a similar screw thread in the socket. The tip or button makes contact with a similar brass piece inside the socket. The socket itself is made of wood, inclosed in a brass box, upon the bottom of which is a screw thread for attachment. The two wires from the main enter the opening and terminate, one in the brass ring which makes contact with the screw thread of the lamp, the other with the flat plate in the bottom of the socket, which is pressed by the tip or button of the lamp cap. In most cases the socket is furnished with a switch or key, by turning which through a quarter of a revolution the current is put on. Within this socket, and making part of the circuit, is a piece of lead wire acting as a safety catch.

The socket is attached to the fixture proper. This, of course, may be of the rudest, simplest description, or it may be elaborated in the highest style of decorative art. A simple arm like a gas bracket is the most primitive form, made either of iron or brass, plain or ornamented. Then a swinging bracket, with two or more arms—an ingenious device allowing the play of the joints without disturbing the current. From that to electroliers and electrolabra, corresponding to gasaliers or chandeliers and candelabra, is but a step. Then these sockets may be attached to hooks, to spring clips, to sharp spikes, and to ornamented drop light stands, and be connected by a flexible conducting core to the supply wire, the object being to change the position of the lamp and to attach it readily where and in any position desired.

Unlike the gas jet, the Edison lamp can be placed in any position without affecting the result. Consequently, they are placed preferably inverted. This not only avoids shadows from the fixtures, but it enables reflectors of any sort—porcelain, tin, either white or polished inside—to be placed above the lamp, and thus to throw down the light which would be otherwise wasted on the ceiling. In this way the amount of light thrown vertically downward is increased at least one half.

THE EDISON LAMP.

It is somewhat strange that carbon, the only substance of any value for the contact surfaces of telephone transmitters, should also prove to be the only substance suited to the light giving portion of electric lamps. Mr. Edison does not employ the carbon so familiarly known in connection with electric lighting, but a new article having different qualities, and remarkable both for the simplicity of the process by which it is made and its efficiency as a light giving body when raised to incandescence by the passage of an electrical current.

The discovery of this new form of carbon was partly accidental, but more the result of Mr. Edison's faculty of seizing upon the slightest suggestion and following it as long as it invites investigation.

Previous to Mr. Edison's invention of the carbon filament, light by incandescence had been obtained from rods of carbon of one to four ohms resistance, placed in closed vessels, in which the atmospheric air had been replaced by gases that do not combine chemically with the carbon. The vessel holding the burner had been composed of glass cemented to a metallic base. The connection between the leading wires and the carbon had been obtained by clamping the carbon to the metal. The leading wires had always been large, so that their resistance should be many times less than the burner, and, in general, the attempts of previous persons had been to reduce the resistance of the carbon rod. The disadvantages of following this practice were that a lamp having but one to four ohms resistance could not be worked in great numbers in multiple arc without the employment of main conductors of enormous dimensions; and that, owing to the low resistance of the lamp, the leading wires must be of large dimensions and good conductors, and a glass globe could not be kept tight at the place where the wires pass in and are cemented; hence the carbon was consumed, because there must be almost a perfect vacuum to render the carbon stable, especially when such carbon is small in mass and high in electrical resistance.

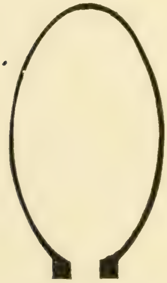


Fig. 81.

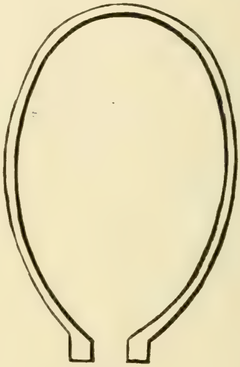


Fig. 82.

The use of a gas in the receiver at the atmospheric pressure, although not attacking the carbon, served to destroy it in time by air-washing, or the attrition produced by the rapid passage of the air over the slightly coherent highly heated surface of the carbon. Mr. Edison changed all this.

The first carbon prepared by Mr. Edison for this purpose was formed of a thread enveloped in a paste made of lampblack and tar, and carbonized at a high temperature. This carbon thread, although not remarkably successful, gave sufficient encouragement to warrant further investigation in the same direction. After the trial of a number of other substances, it was determined that paper, without lampblack or other application, was best adapted to the purpose. Accordingly, in the latter part of 1879, these carbons were made of the quality known as Bristol board. Fig. 81 shows this completed paper carbon of full size, and Fig. 82 the blank from which it was made. By comparing the two figures, it will be observed that the paper shrinks enormously during the process of carbonization.

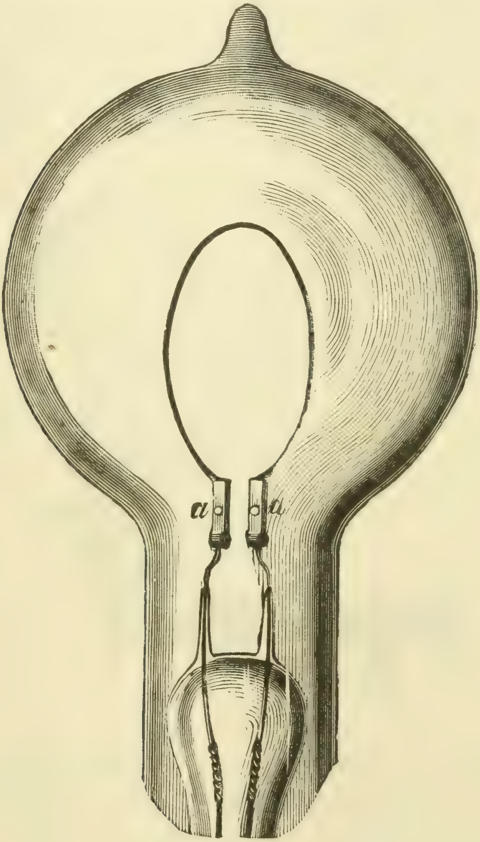


Fig. 83.

The manufacture of these little carbon horseshoes, as they are called, was very simple. The paper blanks, after being cut by dies in the form shown in Fig. 82, were subjected to heat sufficiently strong to drive off by destructive distillation all volatile matters. The paper horseshoes thus prepared were placed with alternate layers of tissue paper in shallow iron boxes, and weighted down with thin plates of ordinary carbon. These boxes were closed by tight fitting covers, and placed in a muffle, when they were raised to a high temperature, which was maintained for a considerable time. The only index of the completion of the process was the crackling of the oxide formed on the exterior of the iron boxes. After cooling, the carbons were removed from the iron boxes and placed between the jaws of small platinum vises *a a* (Fig. 83), which were supported on thin platinum wires blown in the glass base and forming the electrodes. A portion of the glass base and the carbon and its supports were inclosed in a glass bulb, from which the air was so completely exhausted by means of a Sprengel pump that only a millionth part of the original volume remained.

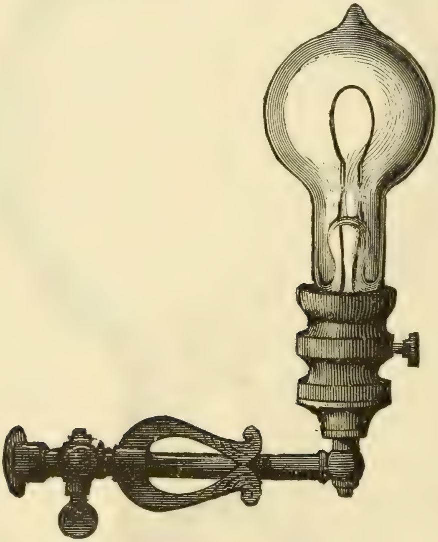


Fig. 84.

Mr. Edison has improved the Sprengel pump so that high vacua may be produced in 25 minutes, instead of the 45 hours consumed in the operation by some of our physicists. The vacuum is so nearly perfect that none of the tests to which the lamps have been subjected so far indicate the presence of the slightest trace of air.

For making his Sprengel pumps and other vacuum apparatus, Mr. Edison fortunately secured the services of an expert glass worker, who was formerly engaged in the laboratory of the famous Geissler, of Bohn.

The electrical resistance of the slender carbon horseshoe was 100 ohms, and, while the lamp shown in Fig. 84 was intended to afford a light equivalent to a single four feet gas jet, it could be forced to give a light equal to that of 8 or 10 such jets.

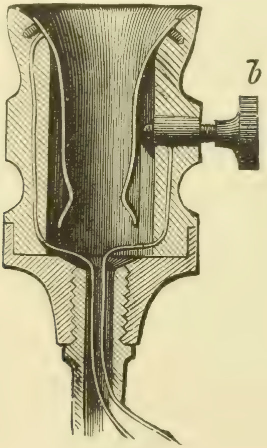


Fig. 85.

One of the most remarkable experiments connected with the exhibition of these lamps was that of connecting one of them with the main electrodes by means of a yard of No. 36 copper wire, no larger than a horse hair. The light was maintained without heating this very small conductor. Of course, a wire of this size is too small to use in regular practice, but it strikingly exhibits the advantage of having a light giving body of high resistance.

This carbon was very tough and flexible, and not liable to be broken or injured by jars, and could not only withstand rough mechanical usage, but it was also proof against injury by suddenly turning on and off the electric current. One of these carbons was subjected to the severe test of applying and removing the electric current a number of times equivalent to 36 years of actual daily use, and yet the carbon was not in the least impaired.

The lamp, in its original form, was as simple as a candle, and, candle-like, it could be taken from its socket and replaced. This could be done while the current was on.

The construction of the socket which supported the lamps in the earlier form is shown in Fig. 85.

The lamp has attached to its electrodes slips of copper, which are bent upward against the sides of the glass, and touch two springs at opposite sides of the socket. One of these springs is connected with one of the electrical conductors; the other spring merely touches the copper strip, and does not form a part of the electrical conductor until it is touched by the thumb screw, *b*, this screw being connected with the second electrical conducting wire. To start the light it is only necessary to turn the screw, *b*, until it touches the spring. To stop the light the screw is turned in the reverse direction. From this it will be seen that the electric lamp is managed easier than a gas burner, as it requires neither lighting nor regulating.

The lamps, as well as their supports, have undergone a good many changes since their invention by Mr. Edison, in 1879.

Greater success attended the use of carbons made from a naturally fibrous material capable of carbonization—for instance, wood formed into proper shape and then carbonized, than from those made from paper; and Mr. Edison found, that the best results were attained by the use of those materials which are fibrous, and wherein the fibres making up the mass of material lie naturally parallel, so that the individual fibres extend from end to end, increasing its strength and obviating danger of breakage from cross or oblique grain.

To produce the best results in giving light it is essential that the carbons should be of uniform size throughout the portion that is rendered incandescent, in order that the radiating surface and resistance should be regular and uniform, insuring even heating and incandescence.

To effect this object Mr. Edison sought to produce a slip or filament for the carbon having parallel fibres and of uniform size; and to this end produced a carbon made of the materials and in the way hereinafter described.

He found that for the purpose of the carbon filament cane bamboo was eminently suited, it having long parallel fibres, with a minimum of cementing or other foreign matters. The cane bamboo is cut into strips, from which the hard, glossy, or silicious exterior and the pithy interior have been before removed, or from which they are now removed. Each strip is then cut or shaved by proper devices or machinery, until its body, or part intended for light-giving, is reduced to the desired form and size, the ends being formed into enlargements, affording a good bearing or surface for uniting the finished carbons to metallic conductors, and the enlargements of the ends are formed entirely upon the side of the finished slip which forms the blank for carbonization, instead of upon both sides. This construction enables the blank, when placed on edge in the carbonizer, to more readily move therein as it is contracted in the process of carbonization. As the material shrinks in the process of carbonization, the finished carbon being smaller than the blank, allowance is to be made therefor in preparing the blanks, and they are made proportionately larger than the size desired for the finished carbon. One or a number of blanks thus prepared are then placed in a suitable carbonizing oven or flask and thoroughly carbonized.

It was found that in manufacturing carbon filaments, for use as the incandescing conductors in electric lights, that they should be carbonized evenly and uniformly, and that their shape should be preserved, in order that the carbonization should be effected without warping or twisting the body of the carbon. As, however, the material contracts largely in the process of carbonization, means are required which, while holding the material in position to avoid twisting or warping, shall at the same time guarantee even and thorough carbonization, and permit the material to move so that the inevitable contraction during the process may proceed without danger of rupturing or otherwise damaging the carbon. Mr. Edison accomplished this object by an ingenious device by which the filament is kept under strain during carbonization, with one or more points fixed against moving, and the contraction proceeds against the strain, which constantly keeps the filament against or in contact with a former, preserving its shape and obviating any risk of warping or twisting. In all, provision is made for keeping the enlarged ends of the carbon flat and in their proper relative position.

The filament used is one cut or formed from a fibrous material, so that the body is perfectly uniform in size throughout its length, and with enlarged ends upon one edge.

In the manufacture of his lamps Mr. Edison found that there is a considerable quantity of air, gas, and aqueous vapor occluded in the carbon filament and the clamps, which are not removed from the lamp by the action of the pump, but have to be driven off by raising the carbon filament to incandescence by the passage of an electric current through the same.

Mr. Edison had invented a method of driving the air from a platinum incandescing conductor by the heat of the conductor, when raised to incandescence by the passage of an electric current through it. In applying this method to a carbon filament, however, some changes had to be made, occasioned by the increased quantity of air, gas, and aqueous vapor occluded by the carbon filament, and also by the fact that the air had to be driven from the enlarged ends of the filament and from the metal clamps wholly by conduction of heat from the incandescent body of the filament. These changes in the method consist principally in maintaining the incandescence of the carbon filament for a longer period than with a metallic incandescing conductor, and in raising the carbon filament gradually to a higher degree of incandescence than with the metallic conductor. With the carbon filament the incandescence finally produced in the process of exhaustion is always higher than the degree of incandescence to which the filament will be raised in use. With the carbon filament (in this respect differing from the platinum conductor) it is desirable that greater flexibility should be given the filament than it would have if the lamp were exhausted simply by the action of the pump, so that the carbon filament can withstand, without fracture, the jars to which it will be subjected in handling and transportation previous to the use of the lamp. This additional flexibility is given the carbon filament by the passage of an electric current through the same, the operation being simultaneous with that of driving out the occluded air, gas, and aqueous vapor. It is also desirable to fix the shape of the carbon filament during the manufacture of the lamp, so that the character of the lamp can be determined, since some of the filaments are warped or bent more or less to one side or the other when raised to incandescence: but by raising the carbon filament to higher incandescence than that to which it will be raised in use, the shape of the filament will be fixed and determined, and will not be changed by the future use of the lamp. This operation, which is peculiar to the carbon-filament operation, is also simultaneous with that of driving out the occluded air, and aqueous vapor.

In carrying out the process, the parts of the lamp are assembled and united. The lamp is then attached to the exhausting apparatus (a Sprengel drop-pump), and when the proper high degree of exhaustion has been obtained, an electric current is passed through the lamp, and by cutting resistance out of circuit the filament is gradually raised to incandescence. The filament is kept for some time at a medium incandescence, the operation of the exhausting apparatus being meanwhile continued. The filament is then raised to a much higher incandescence by the cutting out of more resistance, until the air and gas and aqueous vapor have been driven from the enlarged ends of the filament and the clamps, which can be readily determined by the disappearance of a blue or violet color, which is seen at the clamps while the gas and vapor are being driven off. This high incandescence is considerably higher than that at which the lamp is designed to be used, it being from thirty candle-power upward in a lamp designed to give sixteen candle-power.

A considerable portion of the work of manufacturing the lamps is performed by machinery, by which greater uniformity is insured, but the chain of operations by which the single materials are converted into a finished incandescent lamp is identical in its sequence and character with that of hand-made lamps, and will be understood from Figure 86. The bulbs or flasks are delivered from the glass works in the form shown at No. 1. The first process is to heat the closed end and draw out a hollow cone, shown in No. 2. To this little cone is then fused a short, fine tube (No. 3), by which the envelope is afterwards to be attached to the exhausting apparatus. The bulb then presents the appearance shown at No. 4. The next process is to prepare the glass stem by which the carbon filament is held in its place within the globe, and within which the platinum conductors are fixed that are to join it to the connecting fittings. A piece of tube (No. 5) is taken, and its two ends are drawn or tapered off, as shown in No. 6. It is then thickened up in two places (No. 7), between which it is divided into two separate tubes, shown at No. 8 and No. 9. Two platinum conducting wires are then passed through the tube, as shown in No. 10, care being taken that they do not touch one another. The large end is then heated nearly to its point of fusion, and is squeezed flat so as to cause the platinum wires to be closely imbedded within its substance. The little cranked pieces, shown in No. 11, are then soldered to the ends of the wires, and to these are attached, by an electro deposit of pure copper, the ends of the carbon loop to be presently described. The glass stem with the carbon filament attached is then introduced into the neck of the bulb, to the mouth of which its thickened portion is attached by fusion, so as to form with it one piece of glass. The drawn down end is then trimmed off square, as shown in No. 12, which also illustrates the drawing down in two places of the exhausting tube, so as to form two capillary contractions. This tube having been

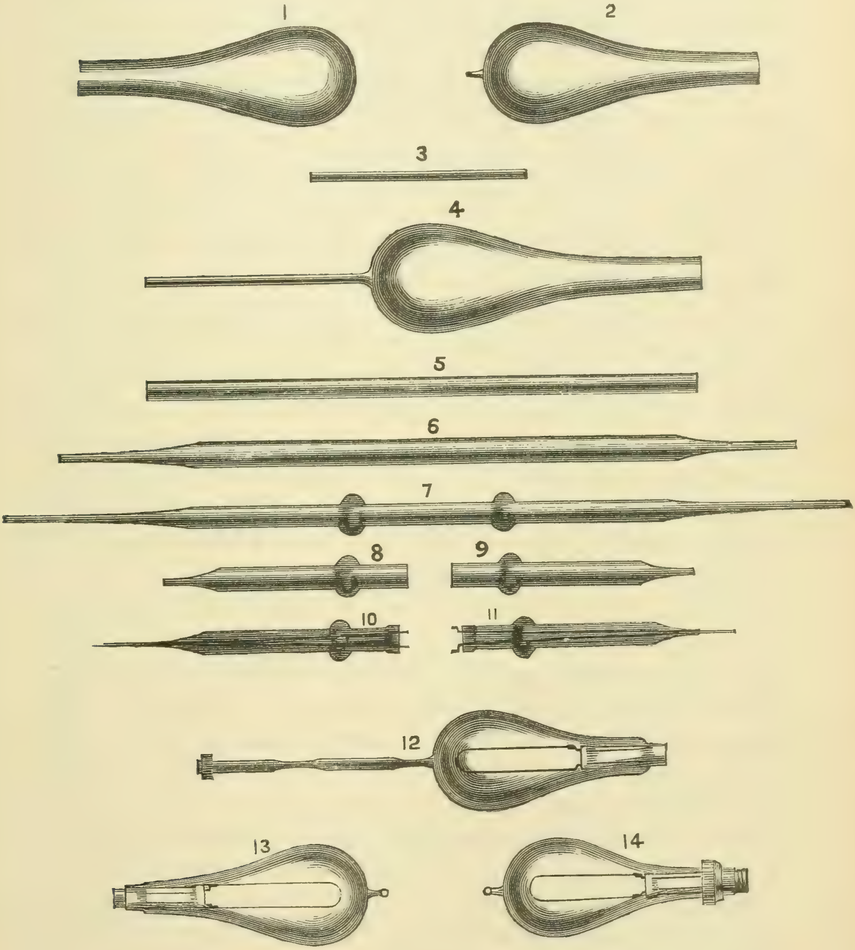


Fig. 86.

attached by a mercury joint to a Sprengel pump, the bulb is exhausted, and when the required exhaustion is complete, the contraction nearest the pump is sealed off, leaving a short length of tube attached to the bulb by a capillary neck, but exhausted to the same degree of internal residual pressure. A second sealing off at this neck renders the hermetic closing of the lamp complete, the object of the double sealing being to guard against any leaking into the envelope at the moment of detaching it from the pump; and by fusing a little globule of glass upon the sealed off point, as seen in No. 13, all possibility of an opening being left into the outer air, however minute, is removed. Nothing now remains but to attach the terminal fittings to the stem of the bulb, and the lamp shown in No. 14 is complete.

In the construction of the carbon filaments in his lamp Mr. Edison, as we have seen, after making a long series of experiments to ascertain the best material to be employed, in which he carbonized a large number of vegetable fibres and tissues, arrived at the conclusion that the fibres of certain kinds of bamboo offered the greatest advantages, both for facility of manipulation and for uniformity of structure, for the preparation of the incandescing conductors. In the Paris Exhibition of Electricity Mr. Edison exhibited a large collection of specimens of fibres and other materials experimented upon, among which there were examples of some twenty varieties of bamboo.

Figure 87 is illustrative of the general operations involved in the preparation of the bamboo, all of which are carried on by boys. Canes of this material are first sawn into pieces of the required length (No. 1), which are, from the character of the plant, naturally tubular. One of these pieces is then split longitudinally down the middle into two half tubes (Nos. 2 and 3), each of which is again split into three narrower strips (Nos. 4 and 5); the hard silicious outer covering peculiar to the plants of the bamboo family is then removed, and the straight fibrous portion is shaved down to a uniform thickness; these stages of the process are represented by Nos. 6 to 9, the latter of which is perfectly straight, flat, of uniform thickness throughout, and cut to the required length. The next step in the process consists in pressing one of these flat strips between two metal blocks which are accurately surfaced to one another, so as partly to project throughout the whole of its length; this projecting portion is then cut away, with the exception of a little piece at each end,

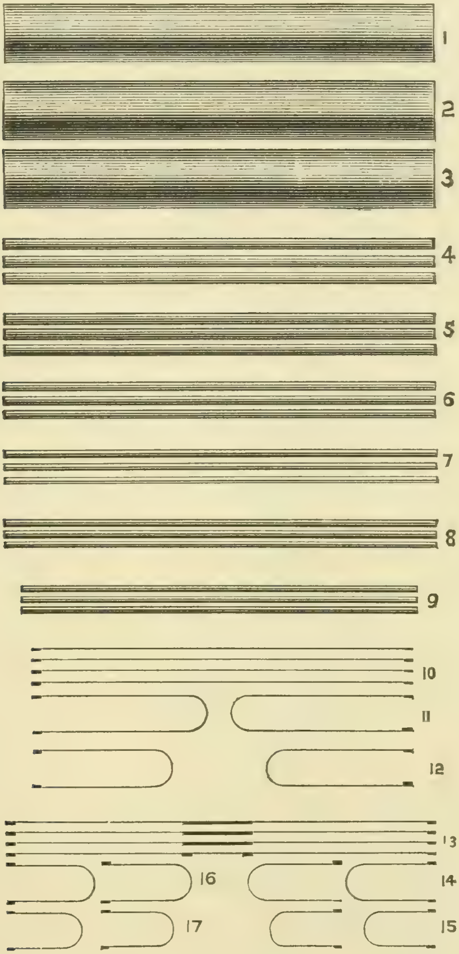


Fig. 87.

so as to leave a fine thread of bamboo fibre having enlarged portions at either end, as shown in No. 10, or if the intended filaments are for the half lamps, an enlarged portion is left in the middle as well as at the two ends (No. 13), so that two filaments may be constructed out of the same bamboo strip. The threads so far prepared are then laid in moulds consisting of nickel plates, in which grooves are cut of the forms shown in Nos. 11, 12, 14, 15, 16, or 17; a flat nickel plate is then fixed over them, so as to inclose them and prevent the admission of air during the process of carbonization, which is effected by raising the moulds with their contents to a high temperature, by placing them in a muffle and heating them to incandescence. When the moulds are opened the filaments are in a condition to be electro-plated to their platinum supports, and introduced into the lamp bulbs; but yet another process is required to confer upon them their perfectly homogeneous and elastic character, as well as their refractory nature at high degrees of incandescence, which are such essential characteristics in an incandescent lamp. This further process is applied when the lamp is attached to the pump, and while exhaustion is going on; it consists in alternately heating and cooling the filament in the Sprengel vacuum, by passing currents of electricity through it of increasing strength, until high degrees of incandescence are reached, and between each increase of current allowing it to cool down, exhaustion going on all the time. By this process, not only are the occluded gases eliminated, but as the fibre is subjected to a far more severe test than it can ever be subjected to in working, none but the fittest survive, and a healthy generation of lamps is insured.

The horseshoe of the carbon has a great advantage over the straight pencil or the voltaic arc, the light being more diffused, and therefore softer and mellower, casting no sharp black shadows, nor giving such intense light as to be painful to the eyes. The light resembles that of a gas jet, excepting in the matter of steadiness, the electric light being perfectly uniform and steady.

The lamps are connected in multiple-arc—that is, the two wires leading from the electrical generator run parallel to each other, and the lamps are placed between and connected with each wire. As Mr. Edison has his circuit arranged, it does not make the slightest difference, so far as the lamps are concerned, whether one or fifty of them are in use; it does make a difference, however, in the power consumed at the generator. The regulation of the current is reduced to the simple matter of varying the intensity of the magnetic field in which the armature of the generator revolves.

The entire lighting apparatus of a house, store, office or factory, consists in the lamps and a few wires. There are no regulators, no complicated switches, no resistance coils to replace the lamps when the latter are not in use.

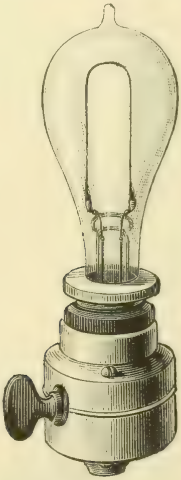
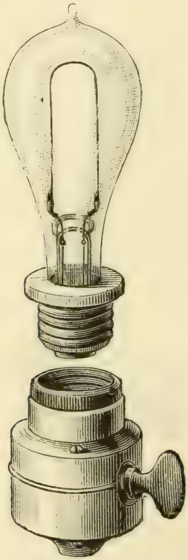


Fig. 88.

The present form of the Edison lamp is shown in Fig. 88. It consists of a clear glass globe exhausted of air, into which is sealed a filament of carbonized bamboo, but a little thicker than a horse hair. Two platinum wires connect this filament with a metallic screw and tip on the plug below, which in turn make electrical connection with corresponding parts of a socket into which the lamp is screwed. The socket may be fitted to any form of gas fixtures. The wires occupying the current are fastened to it; so that when the lamp is in position the platinum conductors and the carbon filament constitute a part of the electrical circuit, the current being conveyed into the lamp by one wire and out again by the other.

Figs. 89 and 90 represent the lamp and socket, and the method of attachment, showing the tap by which the light is turned on and off. After the lamp is once screwed into the socket it needs no further attention or care until the carbon breaks; then the old lamp is taken out and a new one put in. Each light is entirely independent of any other. Hence they may be arranged and controlled singly, in pairs, or in groups of any number, and in any position, inverted or otherwise.



Figs. 89 *and* **90.**

Mr. Edison prefers in his electric lighting to use an incandescent lamp, which shall give a light about equal to a standard gas jet of eight or sixteen candle-power. In order to insure economy of material in the conductors therefor the incandescing portion is usually of very high resistance. The resistance usually given them is sufficient for any desired economy in ordinarily thickly settled localities. For use, however, in sparsely settled neighborhoods—as, say, the outskirts or suburbs of a town or city—it may be desirable to have a lamp, by the use of which still greater economy of conductor is attained. In such localities, in order to lessen the number of lights needed in streets, it may be also desirable to have a lamp in which the volume of light is increased, in order that economy in the erection of lamp posts, etc., may be subserved; and it may also be desirable to use lamps in which the volume of light may be increased in other localities. As there is eventually a limit to the effective life of the carbons used, it seems desirable to so arrange a lamp that the operative life of the lamp may be prolonged beyond the average life of a carbon, to the end that the cost of the labor expended in embodying a carbon in a lamp may be reduced.

To accomplish this object an inclosing globe is used, made and put together in the usual manner. To the inner end of one of the conductors leading into the lamp is fastened a double clamp—that is, one which is **Y**-shaped, a carbon being fastened to each limb of the **Y**-clamp. At the other end each carbon is fixed in an individual clamp, each clamp having its own conductor leading outside of the lamp. The wires leading out of the lamp and the wires leading from a suitable source of electricity are united at a circuit-controlling device constructed so that it may close the circuit through either carbon, the circuit through the other remaining open; or it may close the circuit through both, as carbons in a series; or it may close a circuit through each, the circuits through them being derived or multiple-arc circuits.

When both carbons are used in multiple arc it is evident that the net resistance of the circuit is one half the resistance of one, and a certain size conductor is required. If both are used in series, the resistance is double that of one and four times that of the multiple arc, in which case the conductor may be diminished three fourths. As the volume of light is that of two ordinary lamps, it is evident that a much less number may be used with the same light-giving result. Thus economy in laying main conductors and in the erection of lamps is secured.

It is evident that, as only one carbon may be used at a time, by so using one only at a time the life of a manufactured lamp is practically doubled, for where one carbon has reached its effective limit, the circuit through it is transferred to the other, thus saving the expense involved in sealing one carbon in its globe, the cost of a globe and of its exhaustion. Figure 91 shows one of these lamps arranged with two carbons, and Figure 92 with four carbons.

In this system of electric lighting, wherein the lamps are intended to give only the volume of light of a standard sixteen candle-power gas jet, it is desirable that fittings for carrying and supporting the lamps should be devised as nearly resembling those which experience has shown to be most desirable in gas-lighting as the difference in the lighting agents will admit.

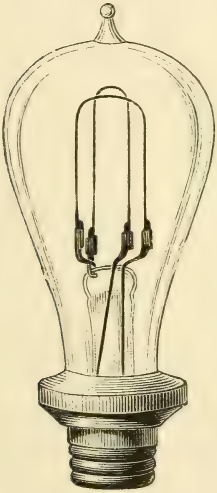


Fig. 91.

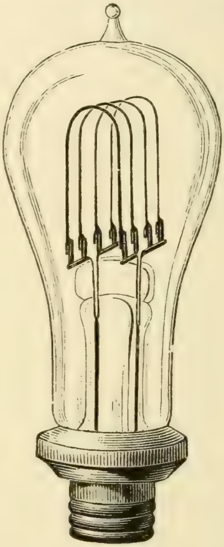


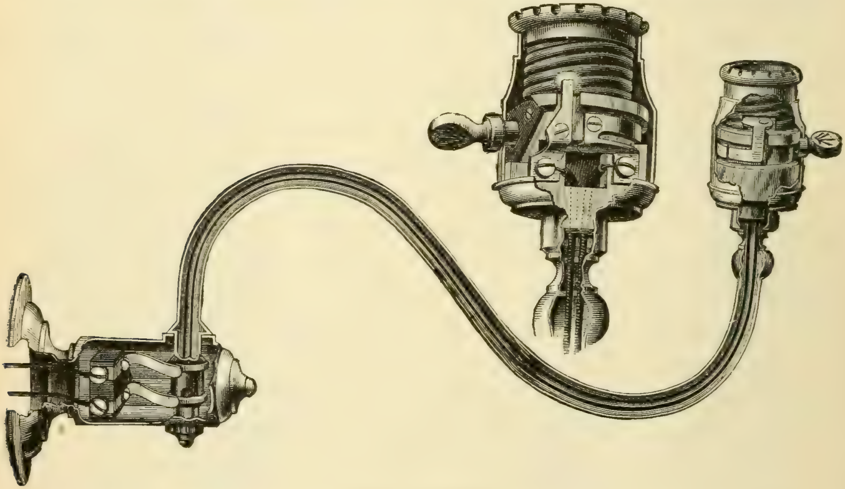
Fig. 92.

One of the most useful devices in gas-lighting systems is the swinging bracket, as it gives a degree of adjustability to the position of the light. Where it has been attempted for any purpose to run an electric circuit through such a fixture in such manner that the circuit should be preserved in any relative position of the arms of the bracket or of a single arm to its base, the connections for such purpose have been exposed. Such an arrangement is defective, in that there is danger of accidental connection or short circuiting, and liability to deterioration of electrical contact from dust and dirt settling upon the contact surfaces.

Mr. Edison has, therefore, provided a swinging or hinged bracket arm for carrying and supporting an electric lamp, arranged to preserve the electric circuit in any relative position of the arms to each other, and of an arm to the base, and in which the connections are incased, so as to be preserved from danger of accidental electrical connection, and so as to be protected from dust or dirt. This he accomplishes as follows: One of the arms is provided with a box or case of suitable size at its end, in which the pivot proper is to turn. To the other arm is secured the pivot, made of insulating material, upon which are secured two separate metal bands or rings, which form the terminals of the conductors passing through this arm. The pivot passes into the interior of the box or case on the other arm through an aperture in its top, the sides of the aperture forming a bearing for the pivot, the bottom of the pivot resting upon the bottom of the box or case, and there secured by a screw passing through the bottom of the box into it and forming a centre upon which it may turn. The conductors in the arm carrying the box pass through the arm into the box, and terminate therein, each in a spring, the two springs being insulated from each other and secured at one end to the interior of the box, from which they are also insulated, their other ends bearing upon the metal bands or rings of the pivot, one on each. As each spring then bears upon its ring or band during the entire rotation of the arm, it is evident that the circuit is always completed from one arm to the other, irrespective of their relative positions, and so an electrical lamp bracket is made possible. The bracket may consist of any number of such arms, pivoted together in like manner.

Instead of springs within the box, an insulating cylinder, with interior metal rings, arranged to coincide with the rings upon the pivot, may be used, or the box itself may be of insulating material, with such rings in its pivotal cavities, or to an insulated pivot, or spindle springs may be fixed to bear upon rings upon the interior of an insulated cylinder or pivot receptacle, or one ring and one spring may be used, a single conductor passing through the bracket, the metal of the bracket and system of pipes being used for the other conductor; but such modifications would only be equivalents of the springs and rings, as described.

Instead of having a circuit controller located upon the fixed support of the bracket, as is the gas cock upon a gaslight bracket, it may be preferable to have it at the lamp itself. In such case a projecting key or circuit controller would be in danger of accidental displacement or breakage.



Figs. 93 *and* 94.

In this arrangement a circuit controller is provided, which has no projecting parts, and in which all the electrical connections are so placed as to be protected and free from all danger of accidental displacement or contact. To this end a circuit controller is made, in which the movable part accessible to the user is simply a plain band or ring of insulating material.

A socket for the lamp is used, consisting of a piece of insulating material hollowed out from the top, and provided at its base with means for its attachment to a pipe, bracket or chandelier arm. Upon the interior of the socket are two metal rings, forming terminals of the conductors, leading through the pipe or otherwise to the socket. Upon the neck or base of the lamp are two rings, forming terminals to the conductors, leading from the incandescing conductor of the lamp, and so arranged that they coincide with the rings of the socket when the lamp is placed therein, so that the circuit is completed, except as modified by the circuit controller, by the act of placing the lamp in its socket. The conductor leading to one of the rings of the socket is interrupted or broken, the conductor leading to a pin upon the exterior of the socket, while a second pin is placed above and contiguous thereto, which is connected to one of the rings of the socket. The socket is shouldered upon the exterior, and upon this shoulder rests a ring of insulating material larger than the part of the socket it incloses, but with a flange extend-

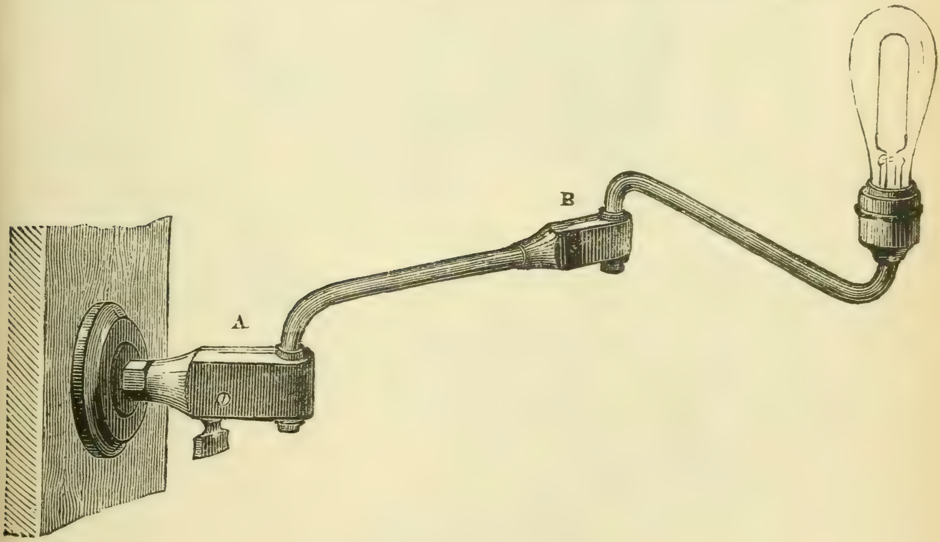


Fig. 95.

ing inwardly at the top, so as to approach closely the upper part, a chamber being formed thereby—the socket forming its inner wall, the shoulder its base and the flange its top. Upon the interior of this ring is fixed a wedge made of a springy piece of metal, bent back upon itself, and of such size that its extreme edges contact with and close circuit between the two pins before noted.

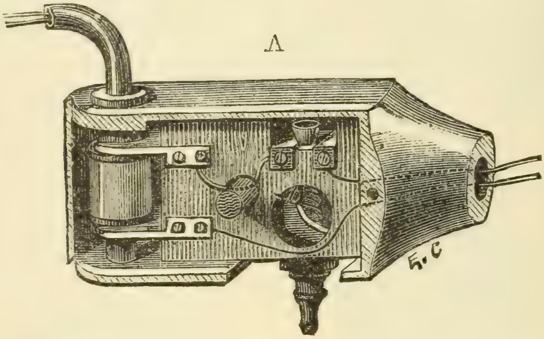


Fig. 96.

Upon the socket within the ring a spring pawl is fastened, taking into recesses cut upon the interior of the ring, so as to limit the movement of the ring upon the socket and also indicate, by the click of the pawl passing into a recess, when the necessary amount of movement has been given. By this arrangement a reliable circuit controller is furnished, which may be placed at the lamp itself, or in exposed situations, without danger of accidental manipulation or breakage. These various

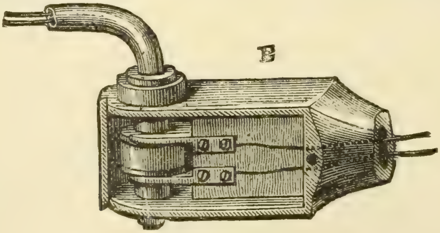


Fig. 97.

arrangements are clearly illustrated in the drawings, in which Figure 93 is a view of the socket and controller in section, and Figure 94 a view of a bracket arm, partly in section, with socket.

The outgoing and return wires enter the bracket at the left and are secured by binding screws to insulated metal springs, which press on circular collars, supported by an insulated support which turns with the bracket. The wires pass thence within the bracket to the bottom of the lamp holder, where they connect with the key which controls the light.

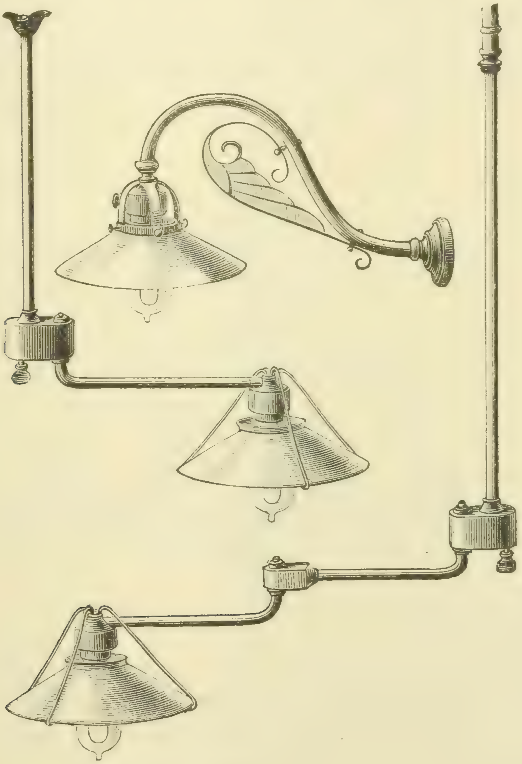


Fig. 98.

The bracket shown in Figure 95 carries two articulations, A and B, and the electrical connections are made through the two plates of the hinges, as shown in Figures 96 and 97.

The lamps are formed of glass globes of ovoid form, cemented into copper sleeves, by means of plaster, and screwed into cylindrical cavities terminating the supports.

Since the lamps will burn equally well in any position, special fixtures are made to support them, pendant, horizontally or vertically, but a pendant lamp is far preferable when applicable. Of the three bracket lamps shown in Fig. 98, the first is rigid, the second swings on one pivot, and the third may be doubled back on itself, or is elbow-jointed; the joints may be bent or revolved at pleasure, without interrupting the current. Figures 99 and 100 represent two three light chandeliers of attractive design.

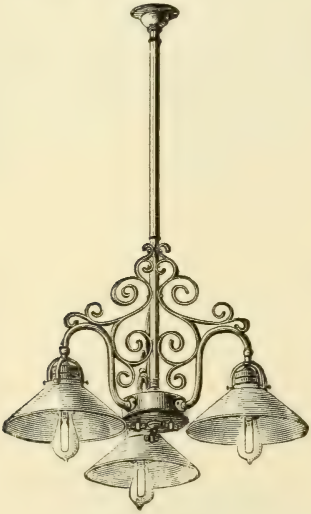


Fig. 99.

As a complement to this system, Mr. Edison has constructed portable chandeliers, represented in Fig. 101, and a current regulator, shown in Figs. 102 and 103, which permits of reducing the light in any desired proportion. It is a carbon rheostat, composed of carbon pencils of different sections, which, as the current passes through one or the other, allows any desired intensity. The apparatus is enveloped in a cylindrical cover pierced with holes to allow of the escape of heat, and surmounted by a lamp which indicates to the eye the desired degree of luminosity. It is worked by a disk, shown separately in the lower part of Fig. 102, and which can be turned so as to bring a contact spring on any one of the supports of the carbon, whose position is indicated by an index and divisions engraved on the base of the cylinder.

There is another application of Mr. Edison's light, intended for lighting galleries in mines. In this arrangement, represented in Fig. 104, the lamp is introduced in a glass receptacle filled with water and held in suspension. Communication of the apparatus with the circuit is arranged in such a way that the points of contact are covered by water, which avoids any danger of explosion in mines infected with fire damp.

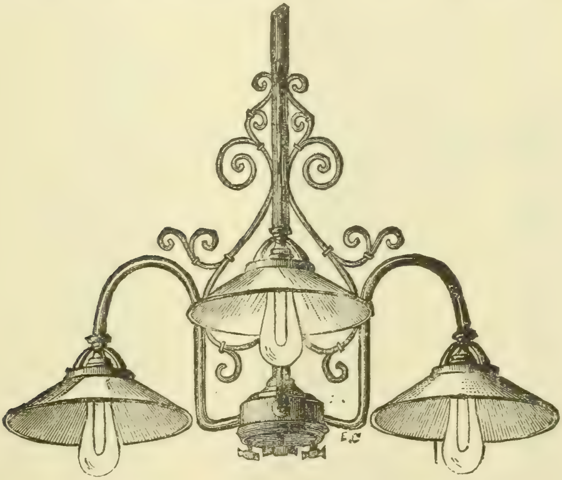


Fig. 100.

In the brackets and chandeliers, keys have been introduced, which will allow the extinction of the lamps separately or together, without causing any spark at the point of rupture or any danger of fire. The movement of the key, A, as shown in Fig.

96, breaks the contact by means of a conical stopper which terminates the screw of the key, and which, when separated from the two plates through which the current passes when the stopper is in contact with them, breaks the circuit at two points, and on a surface of sufficient extent to greatly diminish the spark at the point of rupture.

The lighting of the two salons of Mr. Edison at the Paris Exposition was done by 16 small chandeliers like the above, two grand crystal chandeliers and 80 brackets. Fig. 105 represents one of these chandeliers.

Fig. 101.

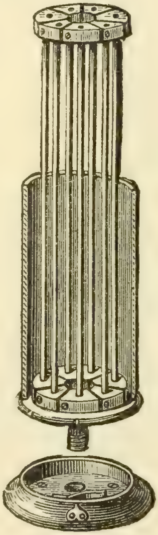


Fig. 102.

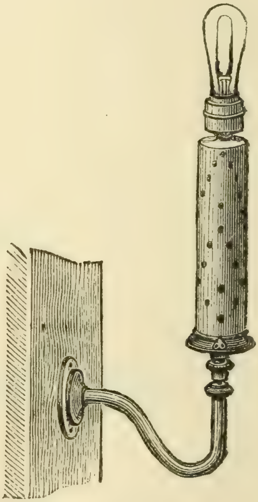


Fig. 103.

The effect was very beautiful, the steadiness being as complete as could be desired; and if, as we have been assured, the price of this kind of illumination is lower, light for light, than gas, it may be considered that the problem is now practically solved, for Edison's system for electric lighting is placed in the same condition as that of gas. He avoids the presence of machines in separate houses, which are always in the way, and which by their very nature require care and management not to be obtained from ordinary servants.

To give an idea of the application of Mr. Edison's systems, we have represented in Fig. 106 the interior of a parlor lighted by the small chandeliers previously described. As is seen, the electric light is projected downward, the best arrangement for reading and writing. This method is preferred by Mr. Edison, but, as can be seen before described, all styles of illumination can be produced with this kind of light, analogous to that obtained with candles or gas jets; it is simply a matter of taste.

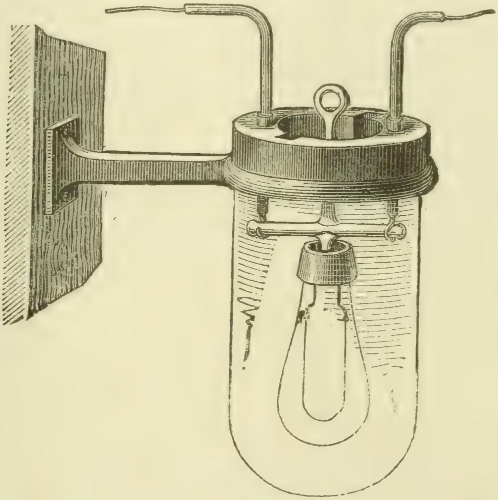


Fig. 104.

The mixture of arc and incandescent lights do not harmonize well together. The latter destroy the effect of the former, and might lead one to believe that the luminous intensity of the incandescent lamp is less than it really is. Again, the difference in the color of the light is so contrasted, that many persons who reproach the electric light for its ghastly aspect, find it too red in incandescent lamps. It is evidently an effect

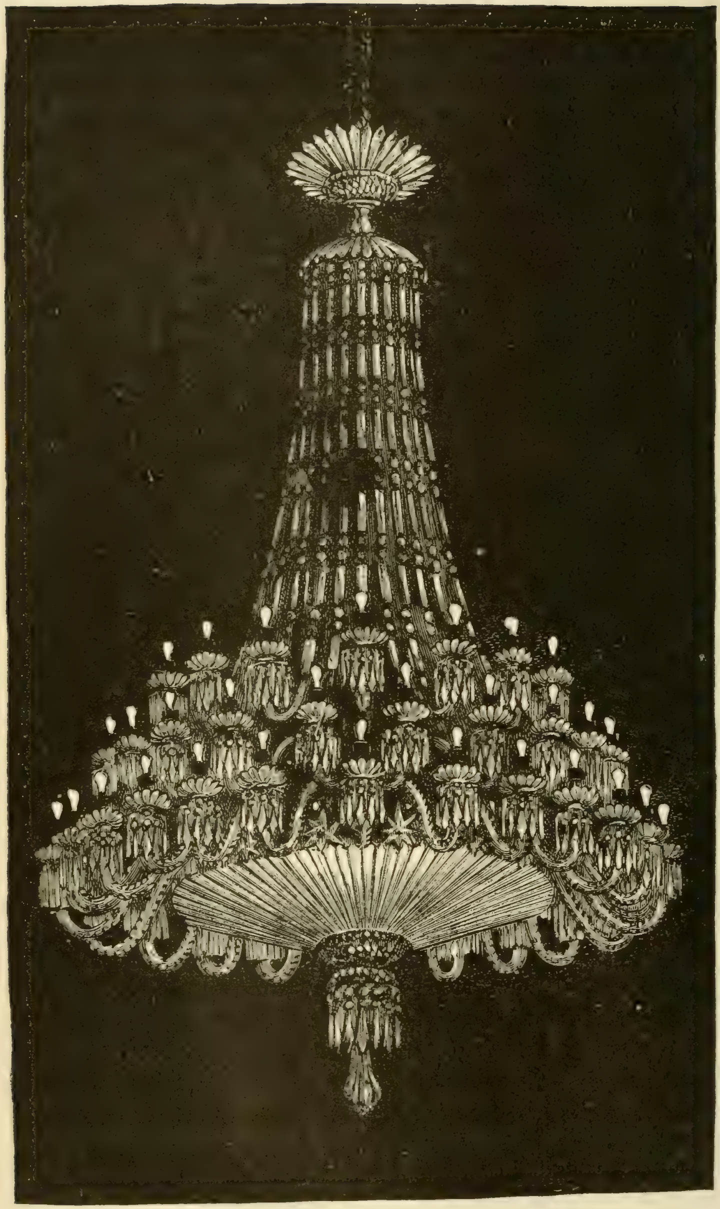


Fig. 105.

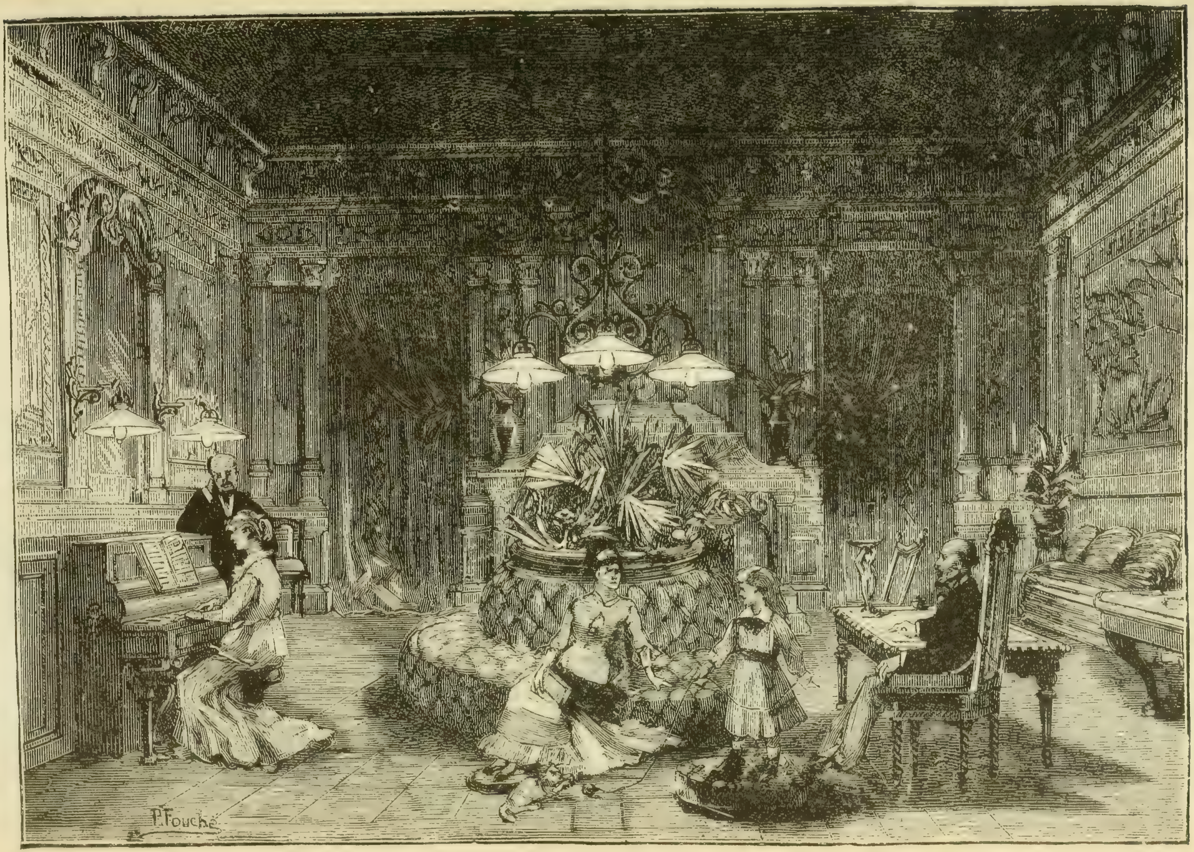


Fig. 106.

of contrast, for the light of incandescent lamps is whiter than that of gas jets, which, nevertheless, the same people find very agreeable. If required, incandescent lamps can give a dazzling white just as well as the others—it is only necessary to employ a stronger electrical intensity—then they lose their peculiar qualities, that of giving a soft light which does not fatigue the eye, and of an easier and more complete subdivision.

The rays of the Edison incandescent lamp make a firmer and more lasting impression on the eye, and one more quickly received by the eye, than the rays of the arc light. An analysis of the rays of the two lamps, the Edison and the arc, accounts for this difference. Place Edison lights on the same pole or other support with the arc light, with the Edison light underneath and the arc light over, the former will practically neutralize the rays of the arc light, so that if the eye be suddenly closed, or if one turns suddenly about and faces in another direction, the impression left on the eye is that of the Edison light and not that of the arc light. One experiment made to compare the efficiency of these two systems of lighting, was to place five incandescent lights underneath a cloth canopy with the sides entirely open, in a public building of large dimensions, lighted throughout with arc lights. From every part of the building, both near by and at a distance, the eye was arrested by these few incandescent lamps, and a distinct impression was made by them upon the eye, although their aggregate candle power was insignificant as compared with that of the arc lights. In small rooms the rays of the arc light pierce the eye with more intensity than those of the incandescent light, but the effect upon the eye is ruinous, and practical experience shows that the eyesight is seriously injured by the proximity of the arc light. Consequently the Edison light, although it will impress itself upon the retina of the eye more strongly than the arc light, should not be placed in small rooms, or even rooms of moderate dimensions, along with the arc light. On the other hand, there need be no hesitation in lighting any two adjoining rooms, one with the Edison light and the other with the arc light, for the Edison light will not only give greater satisfaction on account of its superior purity and steadiness, but will make a deeper and more agreeable impression upon the eye. At the Paris Exposition there was a struggle for public favor between the arc and incandescent systems of lighting. The former gradually but surely lost the day, especially on account of the crudity of its glare. The *prestige* of the arc light was somewhat regained, however, by an invention of Douce & Co., who placed their arc lamps in vases, the light being concealed in the vase, and reflected from a white sheet tightly stretched above it. Enormous candle power was lost by this method, the loss being so great as to make it practically worthless viewed from the stand-point of economy, but the light itself was made, by this device, nearly as moderate, although not as steady as the incandescent light. It is not for the interest of either the arc light or the incandescent light that they should be placed in the same room, especially if it is one of small or even medium dimensions.

The question of durability is a fundamental one in incandescent lighting. It is one of the important features of the Edison system, which attains results in this direction far beyond those of any of the imitators of its lamps. In the tests which are constantly being made many of these lamps burn for 3,000 hours and over, while the average life of all of them is more than 600 hours of actual burning at their normal incandescence of 16 candles. If this normal intensity be maintained, these lamps will be found in ordinary domestic use to last from one to two years in the present state of the art of manufacturing. Improvements are constantly being made in them, however, and it is Mr. Edison's expectation that in a short time the lamp made at his factory, when used under the prescribed conditions, will be practically indestructible.

But the life of the lamp, while an important, is by no means the only important factor in determining the economy and value of the system. It may be said in general that the best system is that which, for each horse power of electrical current, gives the greatest number of effective lamps, and maintains them for the longest period without renewal. As already stated, neither point alone is conclusive.

The Edison standard lamps are made of two sizes, constructed so as to give the light of sixteen and of eight standard candles respectively. These values have been selected because, after most carefully canvassing the facts and statistics of gas lighting, these were found to be the most agreeable to the human eye and entirely adequate for all domestic demands. To make a lamp which, at sixteen candles, shall have a given economy, is vastly more difficult than to make one to burn at a higher incandescence, since the economy rises rapidly with the decrease of temperature. Moreover, the arc light is the simplest of all lights to make, and yields a vastly greater aggregate of light for a horse power, yet it would be not only uneconomical, but practically useless for the great majority of places where light is required.

The following tabular statement, giving the results of the tests of incandescent lamps made at the International Electrical Exhibition at Paris, is extracted from the report of the sub-committee to the experimental commission.

(A.) AT SIXTEEN CANDLES.

	Edison.	Swan.	Lane-Fox.	Maxim.
Candles	15.38	16.61	16.36	15.96
Ohms	137.04	32.78	27.40	41.11
Volts	89.11	47.30	43.63	56.49
Ampères	0.651	1.471	1.593	1.380
Volt-ampères	57.98	69.24	69 53	78.05
Kilogram meters	5.911	7.059	7.089	7.939
Lamps per horse power	12.73	10.71	10.61	9.48
Candles per horse power	196.4	177.92	173.58	151.27
Lamps of sixteen candles per horse power	12.28	11.12	10.85	9.45

(B.) AT THIRTY-TWO.

	Edison.	Swan.	Lane-Fox.	Maxim.
Candles	31.11	33.21	32.71	31.93
Ohms	130.03	31.75	26.59	39.60
Volts	98.39	54.21	48.22	62.27
Ampères	0.7585	1.758	1.815	1.578
Volt-ampères	74.62	94.88	87.65	98.41
Kilogram meters	7.604	9.67	8.936	10.03
Lamps per horse power	9.88	7.90	8.47	7.50
Candles per horse power	307.25	262.49	276.89	239.41
Lamps of 32 candles per horse power	9.60	8.20	8.65	7.48

The Edison lamp, when burning, gives out but little heat—not more than one fifteenth of the heat of a gas jet of equal candle power,—and may at any time be grasped by the hand without inconvenience. While burning at its normal capacity, sixteen candles, it will not in any respect injure, even by the closest contact, the most delicate fabric.

The following are some of the advantages of the Edison Incandescent Electric Lights:

They can be changed in location, with very little inconvenience, at any time, and without the slightest injury to the walls or ceilings.

They are so cheap that many can be inserted, not necessarily to be used at once, but either to be lighted at pleasure, and thus the need of a portable lamp of any kind rendered useless.

A portable lamp, corresponding to a table gas lamp, is made, however, and instead of a heavy gas tube, only a very light wire cord is required to connect it with the chandelier.

No matches are required, since the electric lamps are lighted and extinguished simply by the turning of a key. Not only is expense, and the danger of using matches, thus avoided, but the key may be situated in any part of a house or room; in this way a lamp in the cellar may be lighted in the kitchen; the hall lamp lighted from the basement stairs; or any number of lamps in an apartment, or the entire house, be lighted or extinguished by a key at the bed side, without rising from the bed.

They produce very little heat.

They generate no disagreeable product of imperfect combustion, like gas, or oil lights.

They do not consume the oxygen, and thereby exhaust the atmosphere of an apartment.

They produce no poisonous product of combustion, such as carbonic acid, or carbonic oxide, which are both largely produced by gas and oil lights.

They produce no water of combustion. A gas, or oil light, produces a large quantity of water in an evening, sufficient, if condensed, to partly fill a tumbler.

The electric conductors contain no poisonous, bad-smelling substance to escape in the house, through defective joints, and to cost the consumer an outlay for medical attendance, and a steady running expenditure of seventy cents per month, more or less, for leakage.

They do not emit smoke to blacken the ceilings, or walls, or destroy pictures, by covering them with a layer of oily soot, which cannot be cleaned off.

They can, therefore, be hung below a reflector on the ceiling without impairing its brightness.

The conductors leak no sulphuretted hydrogen to blacken silverware, or lead painted woodwork, or destroy oil paintings.

The sulphuretted hydrogen in gas, when burned, produces sulphurous acid, which destroys the beauty of colored fabrics, pictures, wall papers and draperies. The electric lamp is free from this objection.

Being hermetically sealed in glass globes, nothing can be set on fire by contact with them, and no draughts of air affect their perfect steadiness.

They are not explosive, like oil lamps.

They cannot, like gas, be improperly extinguished, and pour a dangerous vapor into the apartment for hours, which may destroy the sleeping consumer by poison or a violent explosion.

They cannot be extinguished by a sudden draught.

They burn equally well in any position, and a pendant lamp casts no shadow below it.

They require no other cleaning than to wipe the dust from the outside of the small globes.

In the leading stores of the large cities great difficulty is experienced by the condensation on the show windows of the water of combustion from the gas lights. The windows are thereby covered with moisture, or frost in cold weather, which entirely hides the goods from view. The proper use of the electric light will not only obviate this difficulty, but dry goods may be thickly draped all about them, without danger of taking fire from the lamp or the torch, which the careless clerk is intrusted to carry among them when gas jets are to be lighted.

THE EDISON ELECTRIC LIGHTING CENTRAL STATION SYSTEM.

The central station of this system in the city of New York is situated at 257 Pearl Street, in an iron front building, originally erected for commercial purposes, but in which in August, 1881, preparations were begun for this new and important enterprise. Two buildings were purchased by the Edison Illuminating Company for use as a central station, but for the present only one of these buildings is fully equipped.

The district lighted by this system is nearly a square mile in extent, being bounded on the east by the East River, on the south by Wall Street, on the west by Nassau Street, and on the north by Spruce Street, Ferry Street, and Peck Slip. The preparation of this district for lighting involved a vast amount of work, which, generally speaking, may be divided into four branches, namely, the structure or the preparation of the building for the reception and maintenance of the plant, the manufacture and installation of the engines, dynamos and other electrical apparatus, the manufacture and laying of the underground conductors, and the wiring of houses. The work on the central station structure includes the masonry foundation and concrete, a two story iron frame work, vaults under the sidewalk and streets, four boilers, with an aggregate capacity of 1,000 horse power, boiler fittings, two smoke stacks (each 5 feet in diameter and 80 feet high), steam conveyers for coal and ashes, shafting, blowers, and the pumping and blowing apparatus. The station equipment consists of six engines, six dynamos, and the resistance apparatus and regulators. The engines were built by the Southwark Foundry and Machine Company, of Philadelphia, each having a normal capacity of 125 horse power, and a maximum capacity of 200 horse power, making a total maximum capacity of 1,200 horse power. The dynamos were built at the Edison Machine Works, in Goerck Street, New York. The weight of each of these dynamos is thirty tons, making the aggregate weight of the six dynamos 180 tons. The weight of the entire structure and electrical apparatus at No. 257 Pearl Street is about 250 tons, and this weight is distributed so as to average only about 200 pounds per square foot of structure. The boilers in this building, when under full headway, consume 1,680 tons of coal and 4,200,000 gallons of water per annum, equivalent to a daily consumption of about five tons of coal and 11,500 gallons of water.

In the Edison system of furnishing electric light and power to a large number of consumers from one central station, it is essential that the conductors which convey the current to the various translating devices in circuit should be laid underground. Some method, therefore, was necessary by which these conductors could be completely insulated and protected from injury by moisture and other causes. This object Mr. Edison accomplished as follows: The two conductors which form the circuit from and to the central station consist of copper rods, which are placed in iron tubes of considerably larger diameter. Washers of a suitable insulating material, preferably paper or pasteboard, are placed around and between the conductors, so as not to allow any electrical contact between the conductors themselves, or between a conductor and the metal of the exterior tube, and the remaining space is filled with asphalt or a similar non-conducting substance, so that a perfect insulation is attained. The washers or disks before noted are made with notched edges, so as not to close up the entire cross-section of the tube, so as to enable the insulating compound to enter all parts of the tube.

By these devices Mr. Edison was enabled to obtain a complete and permanent insulation between the conductors themselves, and also between the conductors and the exterior tube, the latter at the same time preventing any injury from moisture, dampness, or other causes which might affect the conductors or their insulation, from reaching them.

In laying the conductors for this system Mr. Edison ran two conductors along each side or face of a block. These are termed positive and negative conductors, the positive conductor being the one through which the positive current flows to the lamps or motors, while the negative conductor returns the current to the feeding circuit, and thence through the negative feeding conductor back to the generators. In front of each house, or at any other point where it is desired to make connection with the main iron conductors, they are run into a service box, which is a square box, in which the conductors are laid bare for connection with the house wires. At each corner of a block is a junction box, into which the conductors on the meeting sides of the block pass, and also conductors which cross the streets from the opposite junction boxes. Thus, at the intersection of two streets will be placed four junction boxes, into each of which will run eight main conductors. In each of such junction boxes all the positive conductors are connected, and likewise all the negative conductors, so that a network of intersecting wires is formed. On each face of a block, anywhere between the points of intersection of the main conductors in the corner junction boxes, the conductors are run through a small junction box. In this box one conductor is severed and its ends connected to conductors leading to a safety catch box (Figure 107), located at some point where it can be conveniently reached to replace the safety catch wire when necessary. In this box the requisite amount of safety catch wire or material is placed in circuit, and is burned out when a cross on the main conductors occurs on the particular side of the block where the box is located, thus breaking the circuit and preventing damage. By placing safety catches in this manner in the main conductors on each face or side of a block the accidental cross-connection can be readily located, and by connecting all the main conductors of each class at the corners only the translating devices on the particular side of the particular block are affected by the breaking of the circuit.

The total amount of underground work in this district, including all mains, feeders, bridges and intersections, but not including any house connections under the sidewalks, is about sixteen miles.

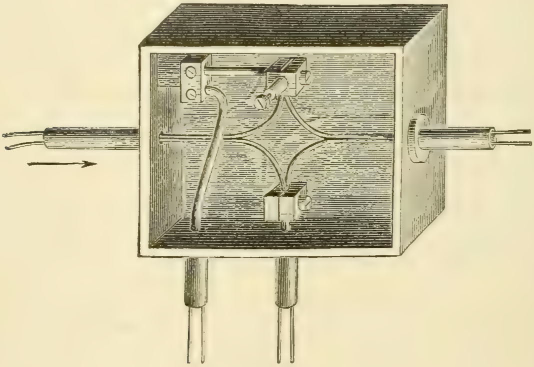


Fig. 107.

While the blocks in this district were being encircled with these bands of copper, the buildings of the district were being fitted with wires leading to the sockets intended finally to receive the electroliers and single lamps, and to such localities as were to be supplied with the electric current for motive power.

The equipment of the central station building was finished, and fire was built under the boilers for the first time on June 29th; on the next day the small engine used for the coal conveyers and blowers was started, and all that portion of the equipment was found to work well. The first steam dynamo was started July 5th; and, July 8th, a satisfactory experiment was made on 1,000 lamps arranged on an upper floor. Subsequently some of the other engines and dynamos were carefully tested with the 1,000 lamps, and the details of their adjustment perfected. The field regulating apparatus was tested, and the electrical indicator, the first ever used on so large a scale, was found satisfactory. This regulator is used in connection with regulating the electric pressure throughout the entire district, so as to keep the candle power of the lamps uniform, irrespective of changes in the number of lamps burning.

One of the most important tests, namely, the strength of the iron structure, upon which rest the six steam dynamos, weighing 180 tons, was finished in July. Two outside engineers, experts in iron structures, were called in to make the tests, and to pass upon the reports, touching the strength of the structure, previously made by the company's engineers. These two experts, Mr. C. C. Schneider and Mr. A. Schweizer, made a favorable report, stating that the "structure is sufficiently strong to carry the loads imposed upon it, which produce a strain of 12,000 pounds per square inch in the extreme fibre of the floor beams, which is the customary strain allowed for wrought iron constructions in buildings."

The entire plant in the district, including the network of conductors and the equipment at the central station, having been tested from a mechanical standpoint, the next thing to be done was to test the plant electrically. This was done by Mr. Edison personally, and many tests and experiments, both of a scientific nature and for the purpose of furnishing data of commercial value in connection with future central stations, were made.

The street conductors having been laid, the service conductors put in, the buildings wired, the dynamos, with their attached engines, put in place, and the district and central station fully equipped, the plant was started and the district lighted up for the first time at 3 p. m., September 4, 1882. Since then the station has been running, day and night, without stopping, and not only has no serious obstacle been met with, but as regards Mr. Edison's part of the work, the result has exceeded all anticipations—the only trouble that has occurred having been caused by purely mechanical matters, such as the regulation of engines, and other usual engineering annoyances, incidental to starting a number of high speed engines for the first time.

Everything relating to the electrical apparatus, as regards both the plant at the central station and the underground conductors, has succeeded perfectly, and if any doubts ever existed, touching the ultimate success of the system, they are now dispelled.

The total network of insulated conductors was manufactured in lengths of 20 feet, and each length that did not, on careful test, show a resistance of at least 150 megohms (150,000,000 ohms) was rejected. Applying the same test to the entire network, as was thus applied to each length of 20 feet, equally perfect resistance would be about 38,000 ohms; and the total leakage in the entire network about 141 foot pounds per minute, or .00427 of one H. P. The conductors have now been underground over two years, and careful tests show that their efficiency, as regards insulation, is but a trifle below the theoretical efficiency exacted from each length tested as above, and that the loss of current, when the present district is in operation at the maximum, will be equivalent only to seven-thousandths of one lamp, or, in other words, to 48-millionths of one per cent. This loss from leakage is so insignificant that, were the entire City of New York lighted with, say, four hundred thousand lamps, the whole loss of current from leakage (taking the actual results in the present district as a basis) would hardly amount to enough current to run a single lamp.

The central station building having been originally erected for commercial purposes, was found to be insufficient in strength to sustain the great weight of the dynamos and their attached engines. Consequently a separate structure was erected within the walls of the building. It consisted of iron pillars planted on heavy plates, resting on three feet of solid concrete and supporting iron trestle work, carrying the heavy iron girders on which the machines were placed. The building is fifty feet in width by one hundred in length, and four stories high, and is divided by a median wall into two equal parts. It is in one of these parts that the machinery is placed. The other part is soon to be fitted up as a duplicate of the one already completed. Beginning with the basement, the area in front, underneath the sidewalk, is used for the reception of coal and the discharging of ashes from the boiler furnaces. In this place there is a special engine, of about twenty horse power, for driving the screw conveyers that carry the coal up over the boilers and deliver it to the stoke hole between the boilers, and the screw conveyers that take the ashes and deliver them to barrels under the sidewalk in Pearl Street. This engine also drives the fan blower which supplies air to the boiler furnaces, and also to the stoke hole to keep it cool and well ventilated. Pipes also lead from the main air trunk of this blower to the dynamos on the floor above.

The boilers—of the Babcock and Wilcox style—four in number, are of 250 horse power each. They all feed into a single 8-inch supply pipe, from which steam is taken through vertical 5-inch pipes to the engines above.

A gallery (Fig. 108) extends over the boiler and stoke hole, from which the visitor may gaze into the depths below.

Each boiler is provided with an injector, and a steam pump is provided with connections for each boiler, so that any or all of the boilers may be fed by it. Water is supplied to the boiler at a temperature above 212°, being forced into a heater that receives the exhaust of all of the engines. By heating the water to this temperature before admitting it to the boilers, the impurities are deposited, and the boilers are supplied with pure water.

Over the boilers is supported the dynamo floor by the trestlework, entirely disconnected from the main building or its foundations. On this floor are six of the largest Edison dynamos.

This generator (Fig. 109) is of the Edison horizontal type, the magnetic field being produced by a battery of twelve horizontal electro-magnets disposed in three rows of four magnets each, two rows being attached by their ends to the upper pole-piece, and one row to the lower pole-piece, the further ends of all being united by a massive heel plate, seen at the back of the figure. The armature is driven at a speed of 350 revolutions per minute, within a cylindrical space bored out of the very massive pole-pieces shown in the front of the illustration, and which are built up of twelve heavy blocks of cast iron, held together by long bolts threaded through them, and by surface coupling plates screwed on to three of their faces. The armature, like that of the Paris machine, is of cylindrical form, and is composed, first of a

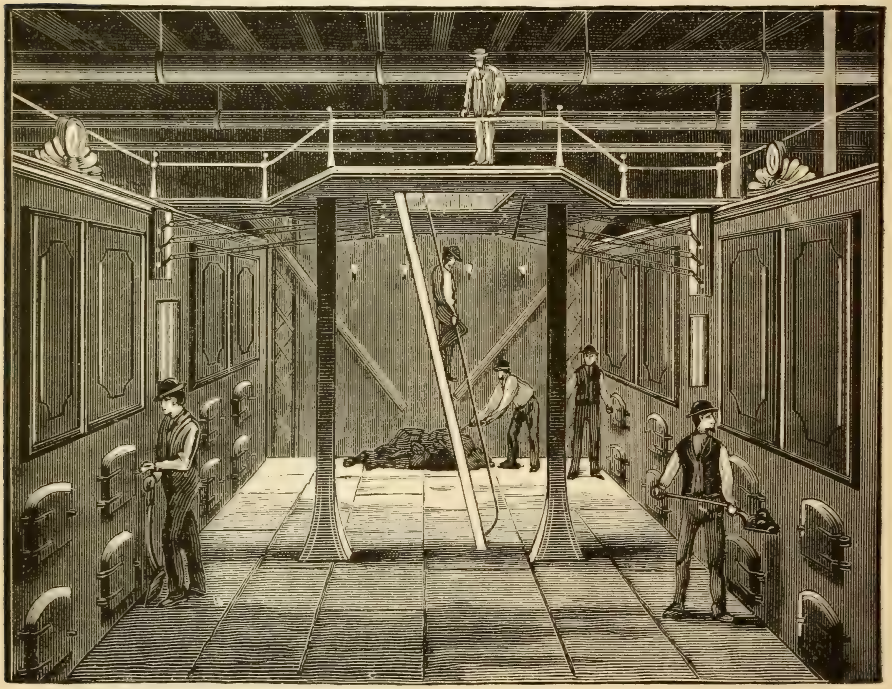


Fig. 108.

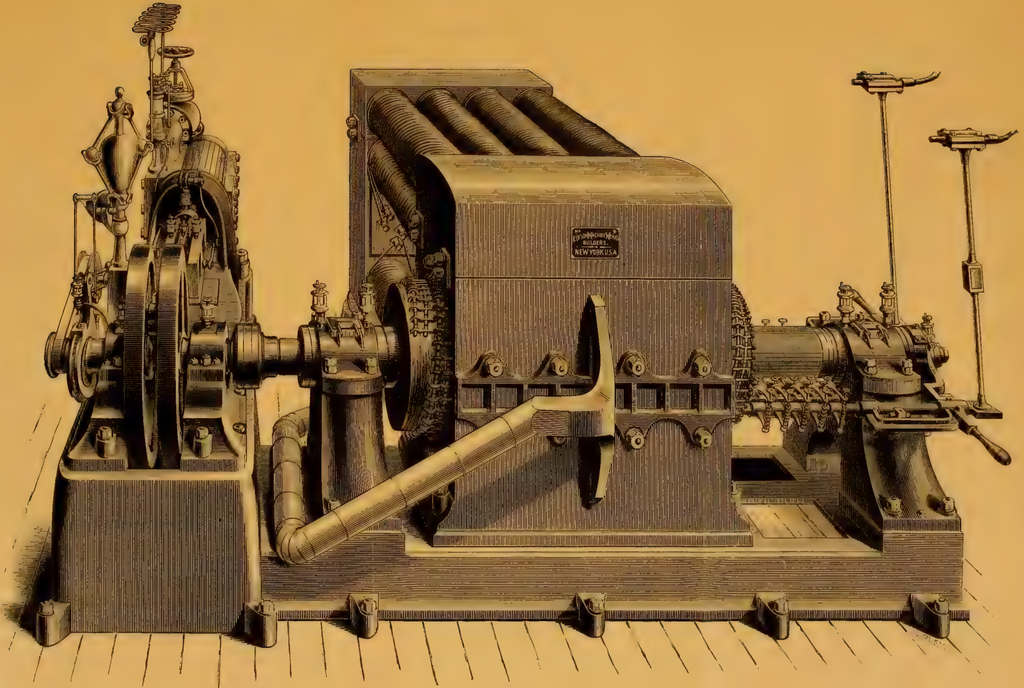


Fig. 109.

core built up of no less than 2,200 disks of very thin sheet iron, alternating with disks of tissue paper, while at every foot measured in the direction of its length, is a disk of thick iron to give stability and rigidity to the armature; the whole is squeezed and bolted together by eight longitudinal bolts passing through all the disks, and through a pair of end plates by which the pressure is applied, and the whole is bushed with a tube of wood, so as to insulate the armature core from the rest of the machine. The induction portion of the armature is composed of 108 straight longitudinal thick bars of nearly pure copper of trapezoidal cross-section, arranged at equal distances around the core and insulated from it. These 108 copper bars are united at alternate ends to as many copper disks, half of which number are strung on to the shaft at one end of the armature and the other half at the other; all the disks are insulated from the shaft and from one another, and the bars are so connected with them that the bars and disks together form a continuous and closed circuit, wound, as it were, longitudinally around the core. This coupling up is effected as follows: Each of the copper bars is connected at each end to the edge of one of the copper disks, and the diametrically opposite edge of the same disk is connected to the corresponding bar at the opposite side of the armature; this bar in its turn is connected to one of the disks at the other end, and the opposite end of this disk is connected to the bar next in rotation to the bar we started with, this again to the next disk at the other end, until all the bars and all the disks have been connected in such a way that a current of electricity transmitted through the armature would pass along one bar, then across the disk at one end, back by the corresponding bar on the opposite side, then across a disk at the other end to the second bar, along that to No. 2 disk, and back on the opposite side to another disk, so that for all electrical purposes the bars and disks together may be looked upon as making up a thick copper coil of extremely low resistance, wound longitudinally over an iron cylinder in a single layer, the various convolutions of which being at equal angular distances apart around the circumference of the cylinder.

In the disposition of the inductive portion of this armature it is identical with the armature of the ordinary Siemens direct-current machine, but the coupling up is simpler, and the course taken by the currents produced is in consequence somewhat different.

The diameter of the armature when complete is 28 inches, its length 5 feet, and its weight over four tons. When it is remembered that this mass is revolved within the hollow cylindrical space between the pole-pieces at a speed of 350 revolutions per minute, it will readily be anticipated that if the heavy bars of copper were attached to the armature only at their ends, which are between four feet and five feet apart, and revolving as they do at a circumferential speed of 43 feet per second, the armature would be speedily destroyed by the bars flying out under the influence of centrifugal force, and coming in contact with the iron pole-pieces which embrace them. To prevent this, the bars are held together at short distances along the length of the armature by coils of steel piano-forte wire bound tightly round the bars over bands of mica, by which they are insulated from them; and some idea may be formed of the high class workmanship and fitting together of this finely constructed machine, when we state that although the diameter of the revolving armature is 28 inches, that of the cylindrical space within which it revolves is only 28¼ inches, thus allowing but one eighth of an inch clearance between the induction bars and the pole-pieces. It is needless, of course, to point out that this accuracy of construction adds very considerably to the efficiency of the machine, by enabling the armature to revolve in a more intense magnetic field than if, through less accurate workmanship, the magnetic poles, to insure the safety of the machine, had to be further off.

The electro-magnets by which the magnetic field is produced, consist of twelve horizontal cylindrical bars of iron about eight feet long, and coiled throughout their whole length with thick insulated copper wire. The coils of these magnets are connected in two parallel circuits of six coils each, and the resist-

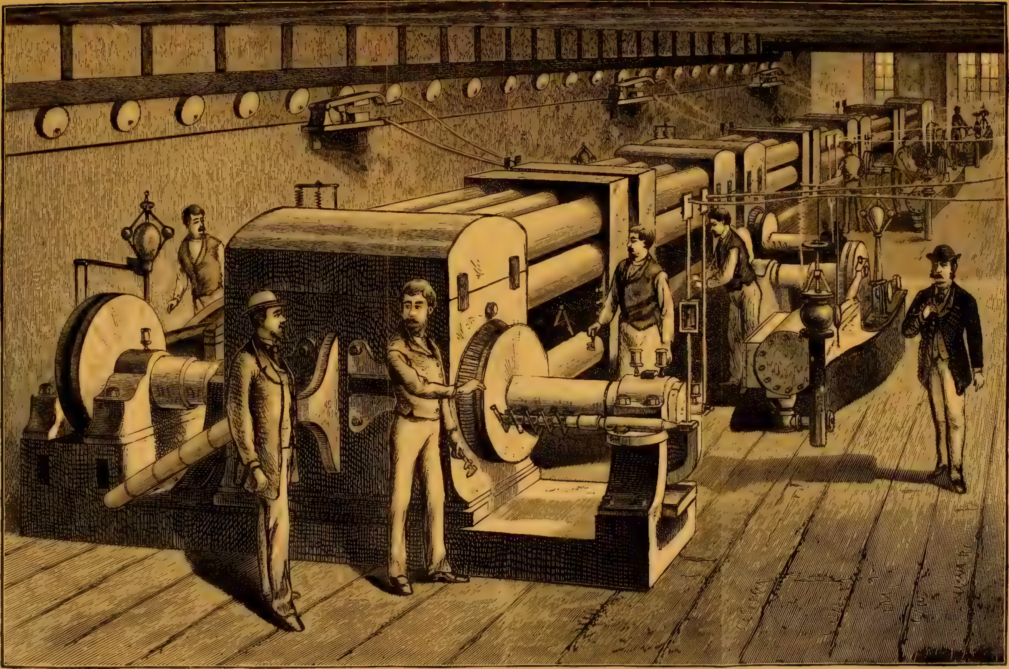


Fig. 110.

ance of the circuit so arranged, and which forms a derived or shunt circuit to that of the machine, is 21 ohms. The resistance of the armature, as will be apparent from a consideration of its construction, is practicably inconsiderable, measuring only about $\frac{5}{10,000}$ of an ohm (.00049 ohm).

The commutator is a cylinder built up of a number of insulated copper sections, as in that of the Siemens and Gramme machines, there being as many copper segments as there are induction bars on the armature, and are connected to them by as many radial copper rods attached in such a manner, that owing to a slight elasticity of the junction there is no tendency for them to be sheared off in the starting and stopping of the machine, a defect which showed itself in the machines of this type which were first constructed. Upon the cylindrical surface of this commutator are pressed two sets of metallic brushes or collectors mounted in spring fittings attached to a rocking arm—shown at the extreme right of the illustration—by which the angular position of the points at which the brushes make contact with the commutator can be adjusted with respect to the neutral plane of the magnetic field so as to obtain the maximum efficiency of the machine.

The motive power is a horizontal engine of the Porter type, of 130 nominal horse power, fitted with a Porter governor and expansion gear, and with a steam pressure of 120 lbs.; it drives the armature which is mounted on the crank-shaft at a velocity of 350 revolutions per minute, the steam being supplied by one of Messrs. Babcock & Wilcox's compound tubular boilers. The weight of the machine, with its engine and bed plate, which is common to both, is over 30 tons.

In order to keep the armature cool, thereby protecting its insulation and keeping down its resistance, there is a small blowing fan driven by the engine, and from this blower three pipes are led which communicate with three air channels cut through the pole-pieces, so as to maintain three jets of air constantly impinging on the middle of the rotating armature, which, escaping right and left, are, during the working of the machine, continually bathing the induction bars with air. The efficiency of this arrangement is proved by the fact that streams of perceptibly warm air are, when the apparatus is in action, continually issuing from the two ends of the hollow cylindrical space within which the armature is rotating.

Figure 110 shows the arrangement of the six large generators in the central station. They are placed in alternate positions with each other, so as to economize room, three of them being connected by heavy copper conductors, with the large copper bars extending along the sides of the room. The bars of like name from the opposite sides of the room are connected at the front of the building, where the entire current from all the machines is entered in two large horizontal copper bars, with which the several street conductors are connected, as shown in Figure 111, one of the parallel street conductors being connected with each of the dynamo mains. In the conductor extend-

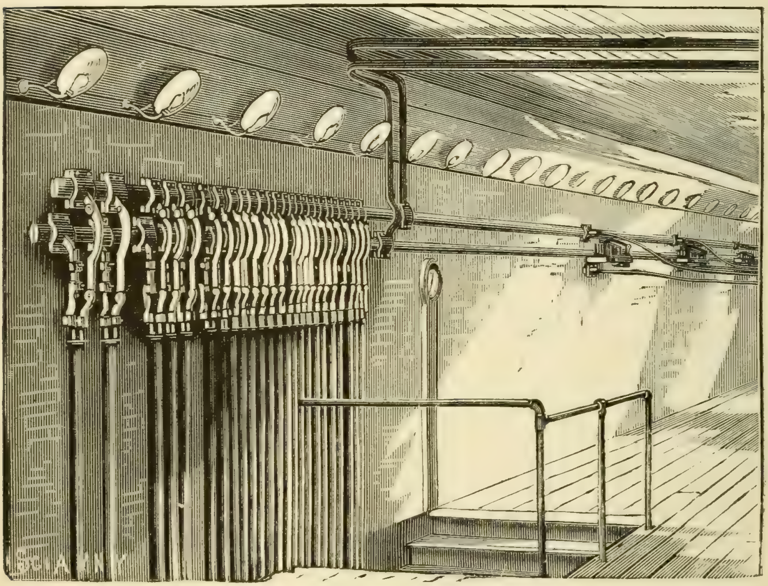


Fig. 111.

ing from the dynamos to the rods along the walls there is a huge switch, shown in detail in figure 112, having three contact surfaces about four inches broad, which wedge between three pairs of fixed contacts. By means of this switch the circuit of any dynamo may be instantly broken. The size of the various conductors vary with the requirements. The street conductors are equal to a copper rod of one half inch diameter, and the service conductors vary, some of them being equal to two and others to ten No. 10 wires. Of the street conductors there are over sixteen miles altogether. The field magnets of the dynamos are placed in a shunt circuit derived from the main circuit, and including a switch and a number of rheostatic coils, one or more of which may be thrown into the shunt circuit, so as to add to the resistance of the shunt circuit from the small fraction of an ohm to seven and a half ohms, which is the greatest resistance necessary

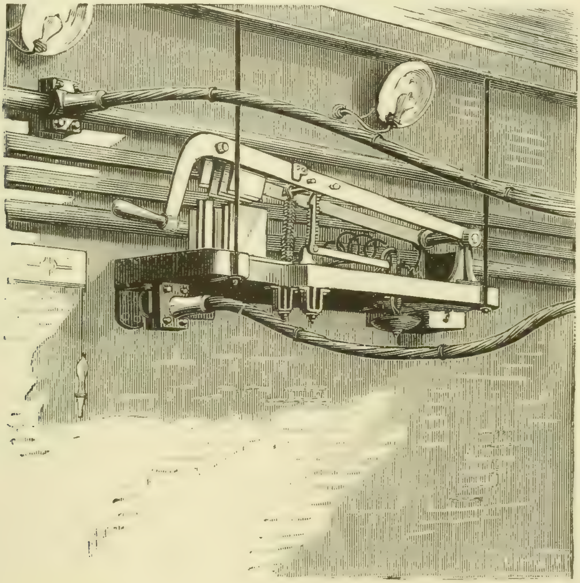


Fig. 112.

to control the current exciting the field magnets, and thus control the current in the main circuit.

The general arrangement of this regulating system is shown in figures 113 and 114. The current which feeds the lamps furnishes a deviation at the machine *bb*, which enters an electric dynamometer, after having gone through a resistance of 180,000 ohms. The electro-motive force is about 103.5 volts, and a difference of one volt corresponds on the scale of the indicating apparatus to three divisions; consequently, for each observed increase of intensity a resistance capable of compensating for it is introduced into the circuit. For this purpose Mr. Edison has established a circular commutator, *e*, with bobbins of different resistance, which permits of an increase of resistance, not in the lamp circuit, which would lead to a loss of work, but in the circuit of field magnets, which weakens their action on the working coil.

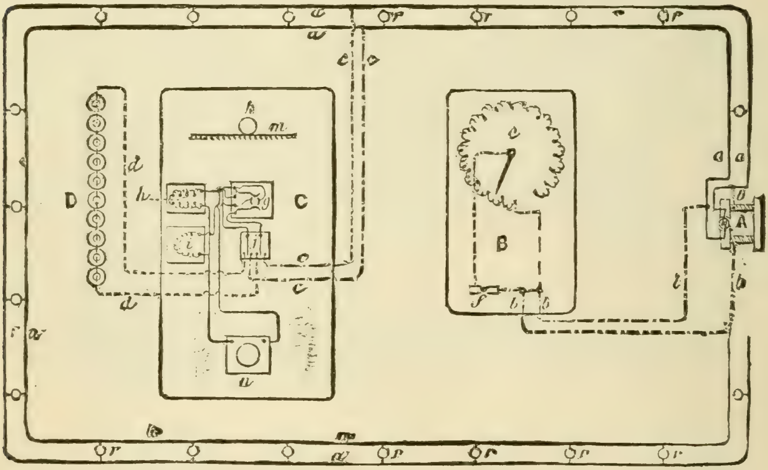


Fig. 113.

EXPLANATION.

A	Dynamo-electric machine.
B	Table of the regulator system.
C	Table of the galvanometer system.
D	Standard battery of 103.5 volts.
aa	Lamp circuit.
bb	Regulator circuit.
cc	Galvanometer test circuit.
dd	Standard battery circuit.
e	Regulator of resistances.
f	Interrupter.
g	Inverser.
h	Variable resistance shunt.
i	Resistance of 50,000 ohms.
j	Commutator of four contacts.
k	Galvanometer lamp.
m	Divided scale.
n	Thomson galvanometer.

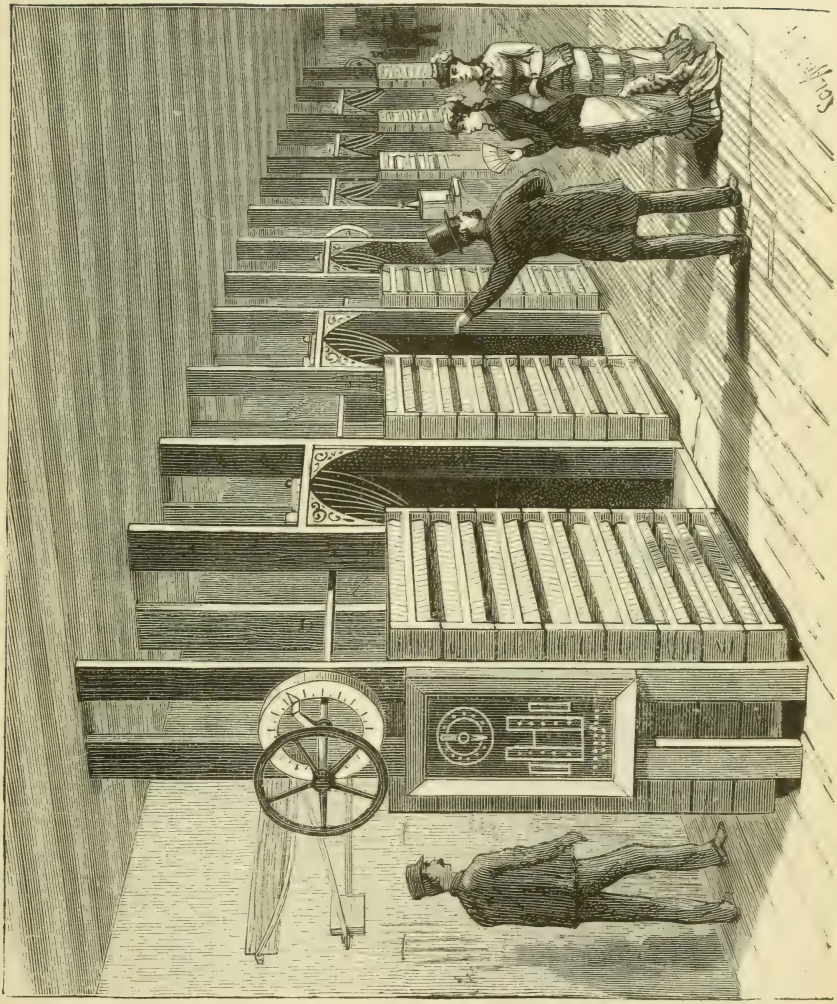


Fig. 114.

There is a set of resistance coils for each dynamo, each set being provided with a circular switch, operated by a horizontal shaft through sets of miter gearing. An attendant is stationed at the wheel at the end of the horizontal shaft, and turns the switches one way or the other, according to the requirements. He is able to judge of the amount of current required by watching an indicator which is provided with two lamps, one red and one blue, with a device for throwing one or the other of them into the circuit, according as the current is strong or weak; neither lamp being illuminated when the current is normal. When the blue lamp is lit more resistance is required in the shunt circuit to reduce the amount of current passing through the wires of the field magnets; consequently, the attendant turns the switch, throwing in one coil after another, until the blue lamp ceases to shine. When the red lamp shines, the switch must be turned in the opposite direction to increase the power of the field magnet and to strengthen the current in the main circuit.

The resistance coils are composed of German silver wire wound upon skeleton bobbins, between which and between the convolutions of each helix, there is a free circulation of air, which keeps the whole system cool. All these coils are coupled together in series, the first being connected to one binding screw of the apparatus, the other binding screw being connected to the regulating lever, which by being moved over a number of contact pieces, arranged in a circle, and connected severally with the resistance coils, can throw into the circuit of the field magnet of the generator any number of the resistance coils, from one to the full number in the regulating apparatus.

From the central station also, the condition of the current affecting the lamps can be controlled by means of a testing photometer, which shows how much the intensity of the current must be diminished or increased to correspond to a given luminous intensity. For this purpose the photometer is mounted on a table placed in a dark chamber. Under and in front of it is placed a scale, arbitrarily divided, so as to indicate immediately

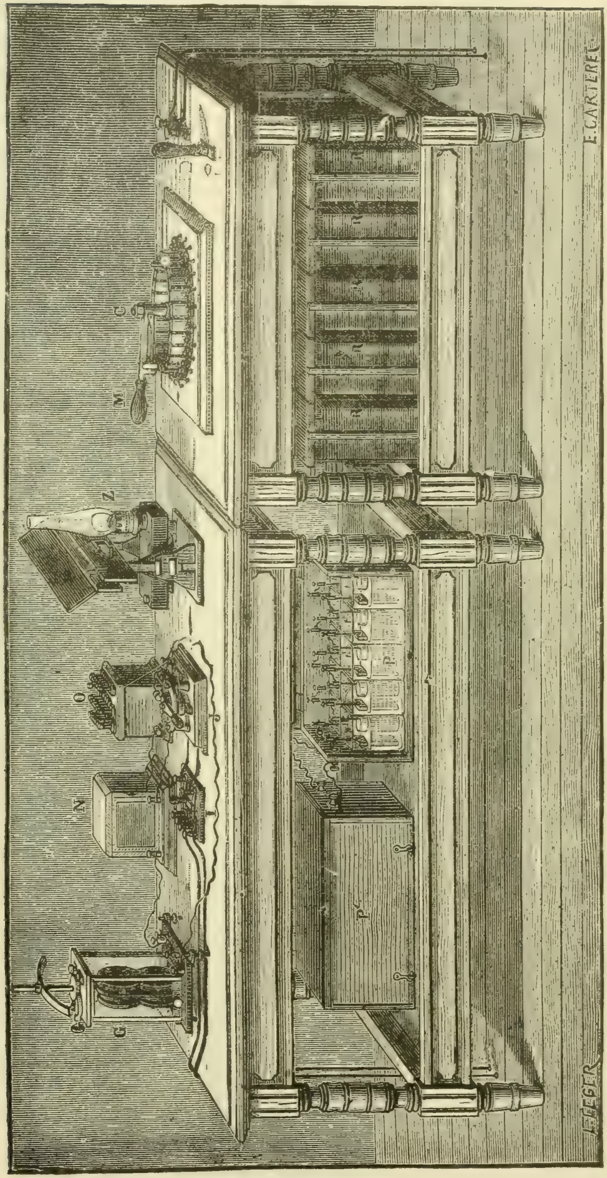


Fig. 115.

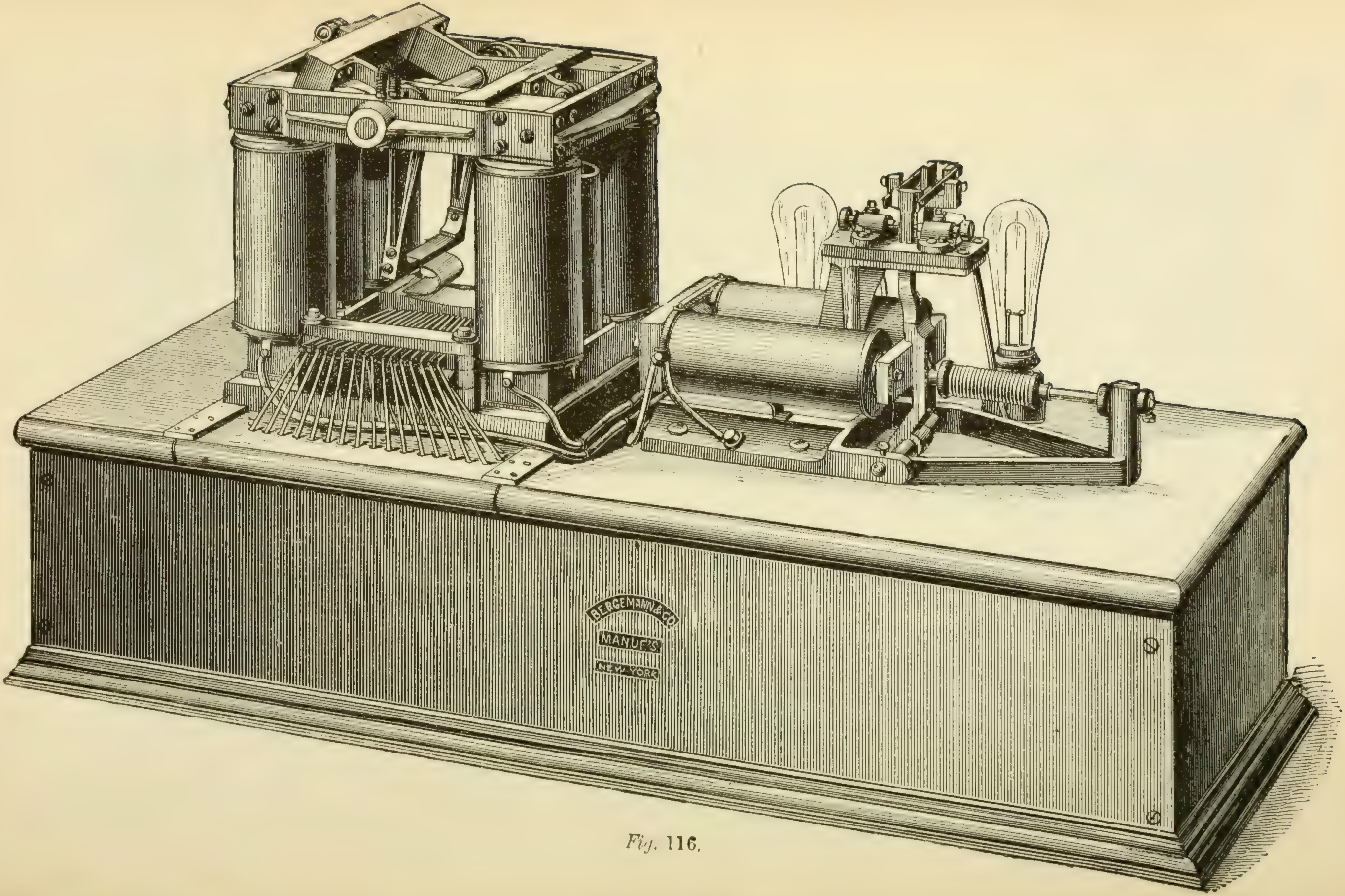

BERGEMANN & CO.
MANUF'S.
NEW YORK

Fig. 116.

the candle power furnished by the current in its normal condition. The left side of Figure 113 indicates the arrangement of the testing bench, with the explanatory table at the bottom of the figure. Figure 115 shows it in perspective.

Figure 116 shows an automatic regulator recently invented by Mr. Edison. To the right of the figure is a relay-magnet, whose lever is centred between two contact points by means of a spiral adjusting spring and two flat springs. The helices of the magnet are wound with German silver wire and are connected directly across the two main conductors, in the same manner as the lamps are connected. When the proper electro-motive force is obtained, the springs are so adjusted that the lever does not touch either contact point. If, now, the potential rises, the magnet is strengthened and the lever touches the front point, closing a circuit containing a large electro-magnet. This attracts an armature lever, the end of which moves over a flat commutator. The movement of the lever throws resistance into the field magnets of the generator, until the relay magnet is so weakened that the springs bring the lever to a central position and open the local circuit. Now, should the potential fall, the relay lever will touch the back contact point, closing another local circuit containing the other large magnet, which, acting as in the other example, moves the lever over the commutator surface, thus throwing resistance out of the field until the relay lever again becomes central. Thus perfect automatic regulation is obtained, the lamps remaining at the same candle power, whether there are a few or a great number of them, or whether the engine within certain limits goes fast or slow. This is the only regulator devised where the lamps are made independent of their number or to the speed of the engine.

As before mentioned, all of the dynamos work in the same circuit when everything is normal, but if from any cause it is supposed that one of them is not doing its work properly, it is immediately disconnected from the main circuit by letting go the huge switch by which it is connected with the main conductors. The switch is provided with a strong spring that opens it instantly as soon as it is released. The isolated machine is now connected with a battery of a thousand 16-candle lamps arranged in two rectangular groups in one of the upper rooms of the building, as shown in figure 117. If the machine brings these lamps to brilliant incandescence, it is in usable condition, and if any trouble exists it must be looked for elsewhere.

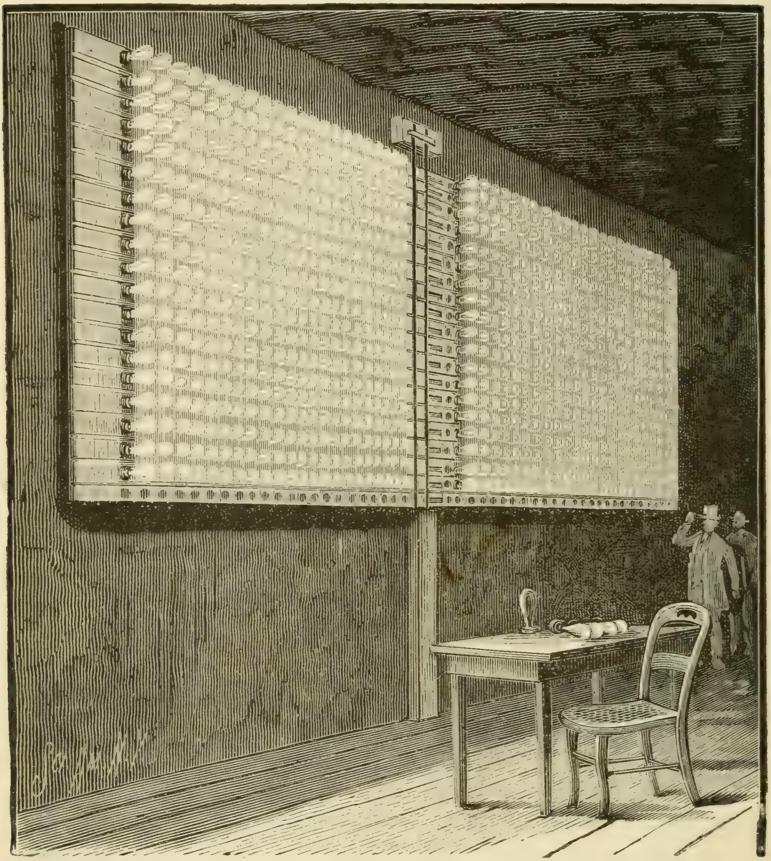


Fig. 117.

On one of the upper floors of this building is a room for testing and for taking a record of the meters employed in registering the amount of current used by the consumer.

The meters are tested by connecting a number of them—from ten to forty—in series with a number of lamps connected in multiple arc, by which means exactly the same amount of current passes through each meter, and, therefore, the same amount of zinc should be dissolved in each cell. If any meter is found to vary from the others and a standard more than one per cent., it is rejected.

The arrangement of the meter described on pages 155 to 157 has been somewhat modified in practice. Instead of a monthly and quarterly record, a monthly record only is taken in each of the two jars—the shunts being exactly alike in each, and consequently as the same amount of current passes in each jar, the same amount of zinc should be dissolved. and thus each jar is a check upon the other. Both jars are taken out of the meter each month by an employee of the company and two others substituted for them. Those taken out are returned to the meter room at the central station, where the two positive plates which have lost in weight are weighed. The difference of the plates in weight caused by electrolysis in the cells during the time they were in the consumer's meter furnishes a basis upon which to calculate the amount of light used. In figure 118, the two cells are shown with the German silver shunt under them. Below the shunt is placed a thermo arrangement which prevents the freezing of the sulphate of zinc solution in winter, or a too low a temperature for accurate registration. It consists of a lamp circuit which is closed by means of a thermo strip of brass and steel riveted together and placed above. The unequal expansion and contraction of the two metals of the strip causes the circuit to be closed when the temperature falls below the desired limit. This throws the lamp in circuit, the heat from which raises the temperature in the meter and acts upon the thermo strip, causing it to open the lamp circuit. Before sending them out these thermostats are adjusted in a refrigerator to act when the temperature falls to 40° Fahrenheit.

It is found in practice that the deposit on the negative plate is somewhat irregular, while, on the contrary, the amount dissolved from the positive plate is very uniform; this plate is, therefore, the one used for weighing and determining the amount of electrical energy consumed.

In order that the same current through the cell shall always dissolve the same amount of metal, it is essential that the resistance and, consequently, the density of the solution, shall always remain the same; it is, therefore, necessary to use a standard solution of a certain definite strength. A solution of ten parts, by weight, of water, to one of sulphate of zinc, having a specific gravity of 1.29 at 15.5° centigrade, is found to be the best in practice, and is, therefore, the one used.

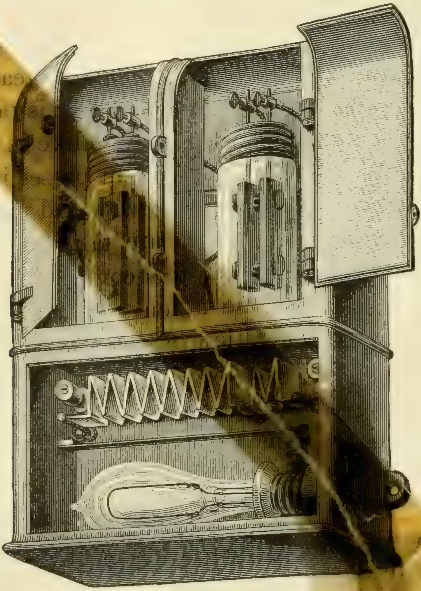


Fig. 118.

The following is the method employed for finding the meter constant for this solution: The resistance of the cell and compensating spool is 9.73 ohms, so $\frac{1}{974}$ part of the total current passing through the meter is shunted through the cell, the remaining $\frac{973}{974}$ passing through the consumer's lamps.

Now, a 16-candle power lamp, having a resistance of 140 ohms, supplied with a current generated by a dynamo whose potential or electromotive force is 103.5 volts, consumes .739 of an ampère of current. Therefore, for one lamp, $\frac{739}{974}=$ .0007587 ampère goes through the electrolytic cell. It has been experimentally determined that one ampère will remove 1.224 grammes of zinc in an hour, and, therefore, as for each lamp in main circuit, .0007587 ampère passes through the cell, one lamp lighted for one hour will dissolve $1.224 \times .0007587=$ .0009286 grammes of zinc; or, as one lamp gives sixteen candles of light, $.0009286 \div 16 = .000058$, which is the loss for one candle-hour, and is the constant sought. To find the number of candles per hour, therefore, $\frac{\text{Loss in grammes}}{.000058} =$ candle-hours.

As the electromotive force is kept constant, the loss in weight of the positive plate will bear a constant ratio to the current which has passed through the meter.

The two zinc electrodes are held a constant distance of one quarter of an inch apart by means of hard rubber clamps. The plates are always carefully amalgamated before weighing and sending out. The plates for the 25 light meter measure three inches in length by one in width and one quarter in thickness. The 50-light meter plates have double the surface of the 25-light, and the 100-light meter plates have double the surface of the 50-light. Calling the resistance of the 25-light cell 1, the resistance of the 50-light cell $=\frac{1}{2}$, and the 100 light cell $=\frac{1}{4}$, and the resistance of the compensating spool consequently varies inversely as the size of the plates. The plates of all sizes are of the same thickness, and are fixed at the same distance apart.

The capacity of a 25-light meter is equal to 25 lamps burning 3 hours, or 75 lamp hours per day; the capacity of a 50-light meter is equal to 50 lamps burning 3 hours, or 150-lamp hours per day; and the capacity of a 100-light meter is equal to

100 lamps burning 3 hours, or 300-lamp hours per day. Special meters are made for consumers using more than 300-lamp hours of light per day.

Each 16-candle lamp requires .739 ampère of current, and as one ampère current develops in one minute through one ohm resistance work equal to 44.24 foot pounds, .739 ampère through 140 ohms requires $.739^2 \times 140 \times 44.24 = 3.383$ foot pounds per minute, or about one-tenth of a horse power. In practice, however, only about seven lamps per horse power are obtained.

The lighting up of a house, as well as all matters connected with the meter and supply of the current, are under the control of the meter department, as are also the catch box plugs which connect the house wiring with the street, as well as the sealing of the catch boxes and meters.

The customer is allowed, in case of any question arising as to the accuracy of the charge for the light, to have one of the meter jars under his control, and he may have the weighing done by any reputable chemist. The meters are always tested before being placed in a house, so that any error in the measurement of the resistance of the shunt or compensating spool may be detected.

When the jars are sent out the plates are weighed and the weight is entered upon the form kept in the central station office for this purpose, as follows:

THE EDISON ELECTRIC ILLUMINATING CO.
OF NEW YORK.

FIRST DISTRICT.

Meter Bottle No. 1,154.
Prepared for use March 17, 1883.
[OUT.] Weight, 88.030 grammes.

To each jar is attached a card containing its number. After the jars are placed in the meter the latter is sealed with lead by a sealing press bearing the company's initials, and cannot be opened without breaking the seal. At the end of a month both jars are removed by the company's inspector and taken to the central office, where the plates are again weighed and entered upon the form, as follows:

THE EDISON ELECTRIC ILLUMINATING CO.
OF NEW YORK.

FIRST DISTRICT.

Meter Bottle No. 1,154.
Returned and weighed April 18, 1883.
[IN.] Weight, 86.214 grammes.

The two forms are then sent to the accountant, who subtracts the weight of the returned zinc from the weight of the zinc when it was sent out (88.030—86.214=1.816), and finds the difference, 1.816 grammes, to be the loss of zinc from the positive plate in a month. The rate of charge for the Edison light is based upon the cost of gas in New York, viz.: $2.50 per thousand feet. It is found that by multiplying the number of grammes of zinc dissolved by 13, the number of candle lights used by the customer will be obtained, and that by charging one dollar per thousand candle lights, the equivalent of the cost for gas for a similar amount of light is obtained. Thus, 1.816 grammes of zinc, dissolved in jar, No. 1,154, would result as follows: 1.816 × 13=23,608 candles, and the bill would be rendered as follows:

EDISON ELECTRIC ILLUMINATING CO.
OF NEW YORK.

OFFICE FIRST DISTRICT, 257 PEARL STREET, N. Y.,......................188

M..............................

Premises No.............................. Street.

TO THE EDISON ELECTRIC ILLUMINATING CO., OF NEW YORK.

For Electric Light supplied from March 17 to April 18, 23.610 Standard Candles at $1 per M Candles, $23.61.

(A sperm candle burning 120 grains of sperm per hour gives one standard candle of light.)

Received Payment for the Company.

Bill presented..............................
Paid.............................. ....

There is no charge to the customer for the use of the meter.

Generally speaking, the bills are found to be about the same as gas bills for the corresponding time. The number of lamps now burning in the first district is about six thousand, although the buildings are wired for a larger number, and there are thirty-two men yet at work wiring buildings every day. Two or three dynamos work night and day, according to the demand for electricity, and the machinery in the station is doing excellent work.

Inquiry has been made in many offices and stores as to how the light was liked, and as to the cost. Opinion seems to be favorable to the light, but its cost is complained of in some instances. Great pleasure was expressed at the purity of the air where the light is burned. In an optician's shop, where ten lamps are burned, the proprietor said that the cost of the Edison light was about twenty-five per cent. more than the cost of the same light for gas, but that the light was better than that from gas, the air of the shop was pleasanter, and, upon the whole, the increase in cost was trifling compared to the advantages of the new light over the old. In this place the light has been in use every day since the 22d of last November, and has never failed.

The central electric lighting station is very complete in all of its appointments. Every imaginable emergency has been provided for: coal bunkers in the top of the building to hold a reserve of coal, water tanks to supply water in case of any deficiency or cessation of supply, thorough protection against fire, and thorough workmanship everywhere.

For convenience in handling the heavy parts of the machines, the dynamo room is provided with a travelling hoist capable of running the entire length and breadth of the room, and having power enough to easily lift the heaviest part of any machine, and of holding or carrying it as may be required. The New York Times is lighted from the Pearl Street station by means of branch underground connections with the regular underground conductors in the first district. The plant consists of 288 lamps, distributed as follows:

Composing Room	115
Mailing "	12
Press "	77
Reporters' "	14
Editorial "	27
Halls	12
Offices	31
Total	288

The fixtures, prepared under special orders from the Times Company, were manufactured by Messrs. Bergmann & Co. The success of the light in the Times building is a good illustration of the entire success of the underground system, because the building is not only at such a distance from the central station as to submit the carrying capacity of the conductors to a severe test, but being also located outside the limits of the district, and beyond the borders of the network of conductors, special conductors had to be laid and connected with the system in a manner not originally contemplated. Everything, however, has worked perfectly, and the light is giving entire satisfaction. Several other newspapers have applied to be connected.

The Western Union Telegraph Company's building, corner of Dey Street and Broadway, is lighted from the Pearl Street station by a special conductor running down John Street, and connected with the network of conductors in the district, at Nassau Street. The building is being wired for 345 lamps, but for the present only about 255 will be used, distributed as follows:

Rooms of the Associated Press	55 lamps.
Operating Room	107 "
Second Floor	55 "
Halls	8 "
First Floor, No. 8 Dey Street	15 "
Second Floor, No. 8 Dey Street	15 "
Total	255

COST OF INSTALLATION OF THE EDISON PLANT.

In the following price list the cost of the dynamo-electric machine, including the regulating apparatus, extra brushes and the requisite number of lamps and sockets for A or B* lights is constant, while the cost for fixtures and wiring is only approximate. The figures are, however, drawn from experience in installing the apparatus, which, taken as a whole, is called the plant.

The only material depreciation on the dynamo is in the wearing of the journals, commutators and brushes, which with ordinary care does not exceed one per cent. per annum. The lamps at their normal candle power are guaranteed to have an average life of not less than 600 hours. The cost of new lamps is one dollar each.

The company will at any time make estimates of the cost of installing a plant, requiring only a detailed plan of the premises to be lighted. This plan should show the proposed location of the dynamo, the location and description of the rooms to be lighted, also the total number of lamps required. An elevation should accompany this diagram, showing the height of ceilings. On completion of a plant they allow one of their men to remain for a reasonable period of time, at their expense, to instruct the purchaser in its use. It may be run by any workman of ordinary intelligence, and requires no more attention than could be given by any engineer without interfering with his regular duties. In their contracts the company guarantee the efficiency of the system.

THE EDISON E DYNAMO FOR 15 A LIGHTS OR 30 B LIGHTS.

Floor space, 25x17½ inches; height, 2 feet 11 inches; pulley face, 3 inches; diameter, 5 inches; revolutions, 2,200 per minute; weight, 700 pounds; 4 horse power.

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* A lights 16-candle power; B lights 8-candle power.

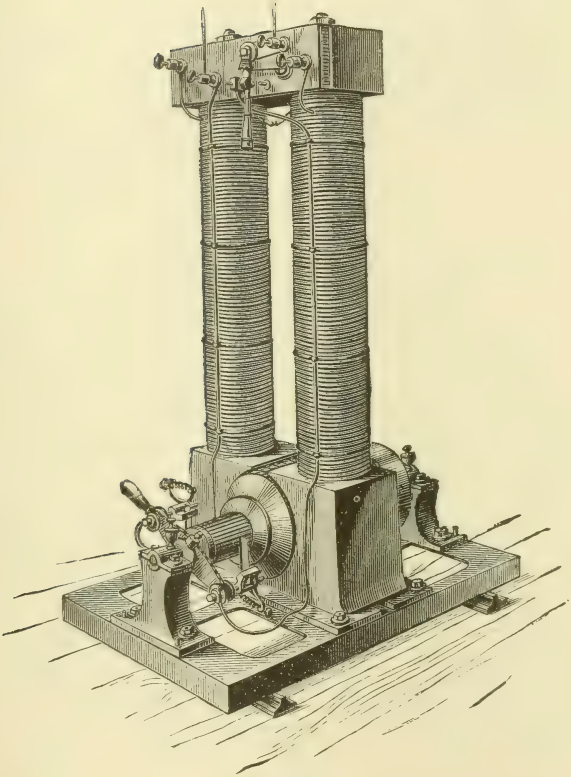

Fig. 119.

Figure 119 is an illustration of the Edison Z dynamo, for 60 A lights or 120 B lights.

Cost, exclusive of Counter-shaft, Belt Connections, and Foundations.	15 A Lights.	30 B Lights.
One E dynamo-electric machine complete, regulating resistance, half dozen brushes, with lamps and sockets..	$500 00	$530 00
Fixtures vary in price from 75 cents to $5.85 per lamp, according to style and finish. For common factory use the cost would probably not exceed 75 cents per lamp.	11 25	22 50
The cost of wire for conductors, cut-outs, safety catches, and other accessories, will vary with distance of lamps from dynamo, also with number of branches and disposition and grouping of lamps. The probable average will be..	50 00	90 00
	$561 25	$642 50

THE EDISON Z DYNAMO FOR 60 A LIGHTS OR 120 B LIGHTS.

Floor space, 45x39 inches; height, 6 feet; pulley, face, 6 inches; diameter, 10 inches; revolutions, 1,200 per minute; weight, 3,000 pounds; 10 horse power.

Cost, exclusive of Counter-shaft, Belt Connections, and Foundations.	60 A Lights.	120 B Lights.
One Z dynamo-electric machine complete, regulating resistance, half dozen brushes, with lamps and sockets.	$1,200 00	$1,320 00
Fixtures vary in price from 75 cents to $5.85 per lamp, according to style and finish. For common factory use the cost would not exceed 75 cents per lamp	45 00	90 00
The cost of wire for conductors, cut-outs, safety-catches, and other accessories for above plants, will vary with distance of lamps from dynamo, also with number of branches and disposition and grouping of the lamps. The probable average will be........	350 00	450 00
	$1,595 00	$1,860 00

THE EDISON L DYNAMO FOR 150 A LIGHTS OR 300 B LIGHTS.

60x39 inches; height, 6 feet 6 inches; weight, 6,000 lbs.; pulley, face, 9 inches; diameter, 14 inches; revolutions, 900 per minute; 19 horse power.

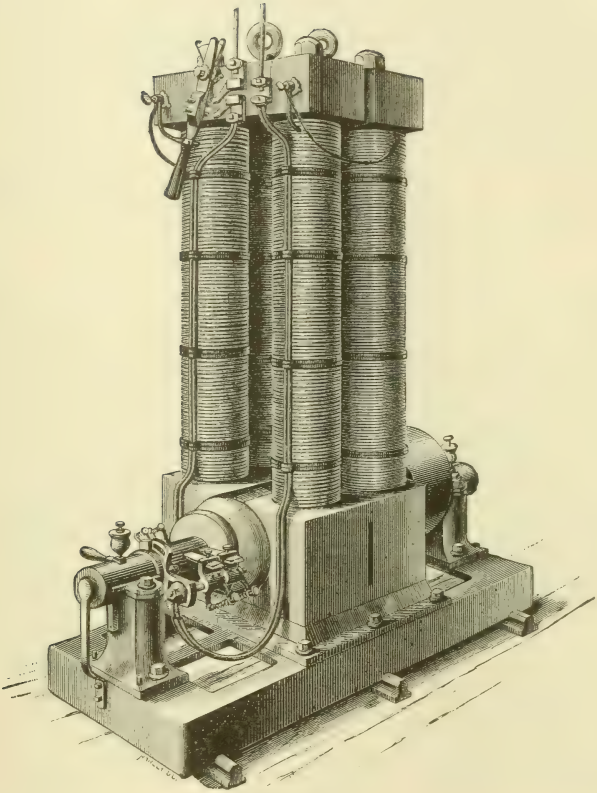

Fig. 120.

Figure 120 is an illustration of the Edison L dynamo, for 150 A lights or 300 B lights.

Cost, exclusive of Counter-shaft, Belt Connections and Foundations.	150 A Lights.	300 B Lights
One L dynamo-electric machine complete, regulating resistance, half dozen brushes, with lamps and sockets.......	$2,000 00	$2,300 00
Fixtures vary in price from 75 cents to $5.85 per lamp, according to style and finish. For common factory use the cost would probably not exceed 75 cents per lamp..	112 50	225 00
The cost of wire for conductors, cut-outs, safety-catches, and other accessories for above plants, will vary with distance of lamps from dynamo, also with number of branches and disposition and grouping of the lamps. The probable average will be..............................	525 00	900 00
	$2,637 50	$3,425 00

THE EDISON K DYNAMO FOR 250 A LIGHTS OR 500 B LIGHTS.

Floor space, 70 x 39 inches; height, 6 feet 6 inches; weight, 8,250 pounds; pulley, face, 9 inches; diameter, 14 inches; revolutions, 900 per minute; 35 horse power.

Cost, exclusive of Counter-shaft, Belt Connections and Foundations.	250 A Lights.	500 B Lights.
One K dynamo-electric machine complete, regulating resistance, half dozen brushes, with lamps and sockets.......	$3,000 00	$3,500 00
Fixtures vary in price from 75 cents to $5.85 per lamp, according to style and finish. For common factory use the cost would not exceed 75 cents per lamp...........	187 50	375 00
The cost of wire for conductors, cut-outs, safety-catches, and other accessories for above plants, will vary with distance of lamps from dynamo, also with number of branches and disposition and grouping of the lamps. From experience in plants installed we find the probable average will be...................................	875 00	1,500 00
	$4,062 50	$5,375 00

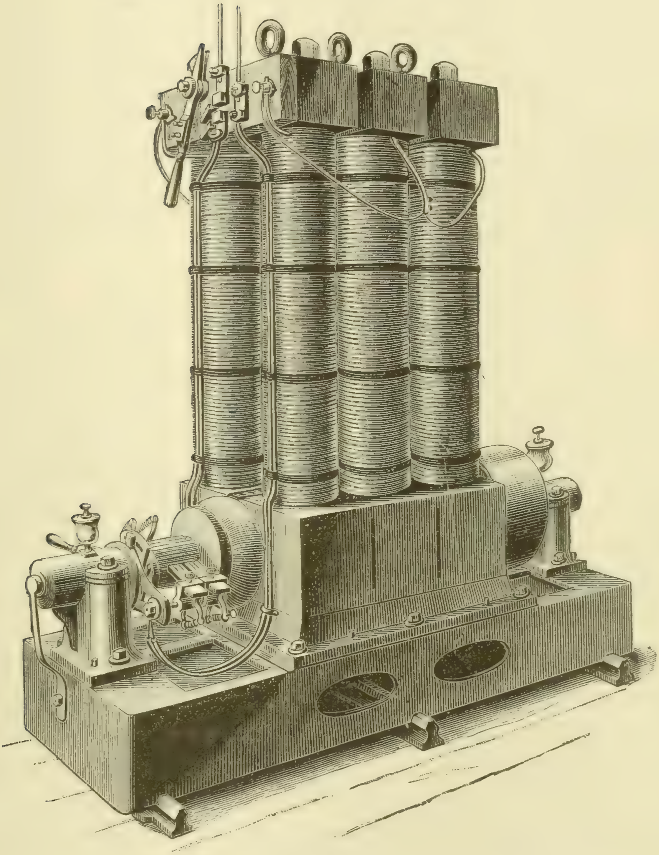

Fig. 121.

Figure 121 is an illustration of the Edison K dynamo, for 250 A lights or 500 B lights.

LIST OF EDISON LIGHTS IN USE.

The following is a list of the Edison electric light plants installed in the United States and Europe:

Country.	Installations.	Lamps.
United States	164	33,050
France	32	2,680
Italy	11	5,777
Germany	28	3,667
Holland	4	1,648
Austria	7	1,724
Russia	14	2,772
Belgium	12	1,268
England	34	8,443
Total	306	61,029

VILLAGE LIGHTED WITH EDISON LIGHTS.

The Edison Company have installed a central station plant at Roselle, N. J., being the first village plant installed. The conductors, the largest being No. 00 wire, and the smallest No. 18 wire, are suspended on poles 30 feet in height, and 130 feet apart, the positive wires, where there are more than two, being on the upper arms, and the negative wires on the lower. Where there are only two mains, the positive is carried on the right going from the station, and the negative on the left. The total length of wire is $8.\frac{76}{100}$ miles. The mains were all completed on January 15th, and on the first test were found to be electrically perfect. The central station is located at the corner of First Avenue and Locust Street, Roselle, and occupies nearly a central position in the district lighted, which radiates about one half mile each way from the station. The building itself is a frame structure of tasteful design, and measures 39 feet 7 inches by 34 feet 10 inches, in the clear. Internally, it is divided into two rooms—a boiler and machinery room. The boiler room measures $15\frac{3}{4}$ by $39\frac{1}{2}$ feet, and the engine room 19 by $39\frac{1}{2}$ feet. The steam is furnished by a 150 horse-power duplex safety boiler, which is entirely enclosed with brickwork. The machinery room has capacity for four K dynamos, each with an independent engine. They have now installed and in use three K dynamos, two of which are run every night. There are 35 houses, wired for over 500 lights, connected with the system, and 150 street lamps. Some of these houses and lamps are half a mile from the station. The platform of the railway depot is lighted by nine lamps in clusters of three each, each of the waiting-rooms is lighted by a three-light electrolier, and the telegraph and ticket office is lighted by a portable fixture and a wall bracket. The current was first turned on January 19th, 1883, since which date the station has been run every night without a hitch of any kind, the lights being perfectly steady and reliable.

STEAMER PILGRIM LIGHTED WITH EDISON LIGHTS.

The plant on the Steamer Pilgrim, belonging to the Old Colony Steamboat Company, consists of 910 lamps, one L and two K dynamos (with a capacity of 11,356 candle-power), and two Armington & Sims engines (one 8½ by 10 B engine and one 9½ by 12 C engine), belted directly to the dynamos. Steam is furnished by a special boiler of about 95 H. P. capacity, with 80 pounds pressure; steam connections are also made with the donkey boiler, and with the ship's main boiler, for emergencies. The dynamos can be used either together or separately, and are regulated by the Edison automatic regulator. The current is taken from the dynamos to the main deck by an Edison electric tube, running vertically on the forward side of a mast to the ceiling of the main deck, and there dividing to each side of the boat. Each branch then runs aft to the centre of the boat, whence all run vertically to the ceiling of the gallery deck. Care has been taken throughout the whole wiring to provide such a system as to prevent the lights from being extinguished by an accident to the boat, and, to that end, the wiring has been divided into four sections, each of which is entirely independent of the others, and each is furnished with its own proper complement of safety appliances. Each fixture, whether it be a large chandelier in one of the saloons, or a single light in a stateroom, is also furnished with the Edison safety catch. The grand saloon is illuminated by one large chandelier of 36 lights, and two chandeliers of 27 lights each, each chandelier having four tiers of lights, every tier being controlled by a separate switch, and each chandelier being supplied from two separate sections of conductors. There are also on the saloon deck three small electroliers of 8 lights each, four newel-post fixtures, five two-light brackets in each side passage, and four additional two-light brackets at other points. The gallery deck receives the greater portion of its light from the large electrolier in the main saloon, and has also one eight-light, and one twelve-light electrolier, five brackets in the side passages, and one four-light bracket aft. The remainder of the lamps are distributed in the social hall, the quarter deck, dining saloon, freight deck, engine and boiler room, fire room, barber's shop, captain's office, kitchen, pantry, officers' quarters, staterooms, and miscellaneous portions of the boat, there being no gas or other light on the vessel.

The plant is the Edison A system, with an electro-motive force of 110 volts, the lamps used being of 16 and 10-candle power, as required. The total number of lamps are distributed as follows:

	16-candle power.	10-candle power.	Total.
Gallery and Grand Saloon.......	199	250	449
Main Deck	131	138	269
Dining room and Aft Cabin......	32	110	142
Forward Cabin	14	36	50
	376	534	910

EFFICIENCY AND COST OF THE EDISON LIGHT.

The following extracts are from a letter written by Mr. F. E. Clarke in reply to an inquiry as to the efficiency and economy of the Edison plant in the Pemberton Mill, Lawrence, Mass.:

We put in one Z dynamo, 65 A or 120 B lights, in October, 1881, and at first tried the 120 B lights with it, lighting 120 looms, with one light to a loom. From what I saw in New

York I became convinced that the A lamp, using half as many, would serve us better; consequently, I made the change, getting 65 A lamps in running order in January, 1882. With these A lamps we lighted 130 looms. The many advantages of the light, some of which were—almost perfect condition of the atmosphere when using no gas jets, discrimination of colors, little imperfections in weaving remedied more quickly by the weaver, a better diffusion of light among the machinery, enabling quicker renewing of warps in looms, and quicker repairing of breaks in warps or machinery, all of which were experienced in using the light through the winter of 1881 and 1882, and up to September of 1882—decided me to increase the number of lights so as to light wholly two entire weaving rooms. I therefore contracted for 2 L dynamos, 150 lights each, giving me in all 365 A lights. These were all in operation early in November, 1882, and have been in use continually since. After a week's use I had taken out of the two rooms all of the gas jets, except 4 in each room, which are used in case of stopping of electric lights—that no panic may be occasioned among the help. The electric machines are driven by the regular power of the mill (water wheels), and once in a while a short stop is necessary from some breakage of shaft or large belt, etc.; hence, the few gas jets spoken of above. The operation of the machines and lights through the mill, thus far, has been very satisfactory. We make colored goods largely. Our weave rooms are wide, and in dark days, and in fact, nearly, if not quite, every day we have used a part of the lights all day. The difference in the atmospheric condition of the rooms, from what they were when we used gas, is almost indescribable. In the evening, when all lighted, the air is as pure to the health and sight as it is in the full sunlight.

I have the light at my desk in the office, and its steadiness, and the absence of heat rays, make it very pleasant, and I am able to write and read, as long as I choose, without any inconvenience to my eyes.

Now for comparative economy of gas and electricity:

We used during January, 1883, 135 lamps ten hours per day, and 230 lamps, 2 hours per day, being equivalent to 181 lamps, 10 hours per day. As we displaced 2 gas jets with each A light, we displaced 362 gas jets, with 181 A lights. 362 gas jets, 10 hours, 4 feet per hour, give 14,480 feet gas, which, at $1.65 per thousand = $23.89, as daily cost of gas to obtain a poorer light.

The electric plant cost $6,825.60. 12 per cent. of $6,825.60 for interest and depreciation, one day....	$2 73
Eight mills per H. P. per hour, 181 lights 28 H. P.....	2 24
Lamps, 181 lights; renewal, 4 lamps daily............	4 00
Extra cost, man and oil, etc.........................	1 25
Total daily cost of 181 lamps, 10 hours per day....	$10.22

MR. EDISON'S AWARDS BY THE INTERNATIONAL CONGRESS OF ELECTRICIANS, AT PARIS.

The congress subdivided its work among juries, to each of whom certain special subjects were assigned. The highest award the congress could give was a diploma of honor. The final award to Mr. Edison, by the several juries, was three diplomas of honor, two gold medals and a silver medal. Pursuant to usage, however, the congress reserved the right to reorganize awards, so as to give to each exhibitor the highest award which he had received in any one class, and the congress therefore approved the recommendations of the juries, and itself awarded a diploma of honor to Mr. Edison. Altogether there were only eleven diplomas of honor granted by the full congress, and Mr. Edison received the only one which was awarded for an incandescent electric light. In addition to the foregoing awards, Mr. Edison received from the French government the decoration of officer of the Legion of Honor.

CHAPTER IV.

THE MAXIM, SWAN, BERNSTEIN AND LANE-FOX INCANDESCENT ELECTRIC LIGHTS.

THE MAXIM INCANDESCENT LAMP.

In Mr. Hiram S. Maxim's earliest form of incandescent lamp he employed platinum for the light-giving body.

Figure 122 shows this lamp in perspective; Fig. 123 is a vertical section. The spring, A, which clamps the lower end of the platinum strip, is secured by a binding post to a vulcanite block attached to the base of the iron standard. An insulated platinum tipped rod, B, extends through the base of the standard, and is connected with one terminal of a resistance coil, C, concealed in the base. The other terminal of the coil is in electrical communication with the iron standard. A threaded rod, D, extends downward through the upper end of the standard, and has at its lower end a clamp for holding the upper end of the platinum strip. The rod, D, is adjusted by the nut which bears on the top of the standard, so that when the platinum foil is cool, the spring, A, does not touch the rod, B.

One electric wire being secured in the binding post that holds the spring, A, and another being connected with the vertical standard, the current passes through the spring, A, the platinum strip, the rod, D, and the vertical standard, heating the platinum to incandescence. Should the current increase so as to bring the temperature of the platinum nearly to the melting point, the strip expands until the spring, A, touches the end of the rod, B, when a portion of the current passes through the resistance coil, C.

When the temperature decreases, the platinum contracts and breaks the contact between A B.

This lamp was invented by Mr. Maxim in 1877, but was

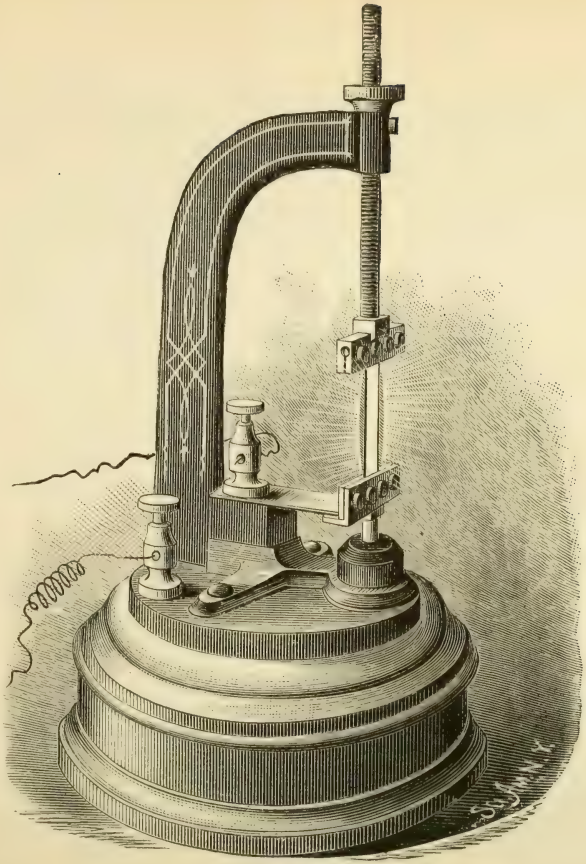

Fig. 122.

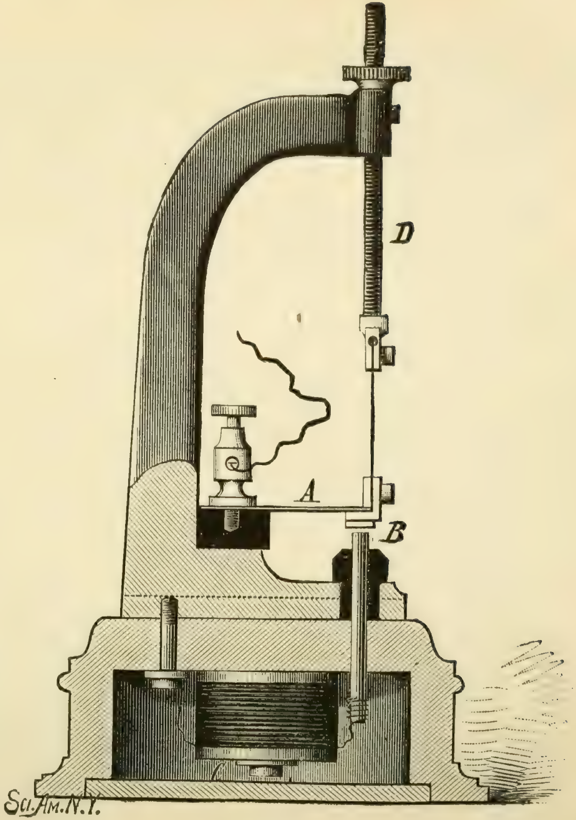

Fig. 123.

never patented, because he found by experiment that it required a very much greater expenditure of power to produce a given light with it than was required with the carbon points.

Subsequently Mr. Maxim produced the lamp which is shown in Fig. 124. This lamp resembles the Edison and Swan lamps in its general features, but differs in details of construction, and especially in the method by which the carbon conductor is made. The Maxim carbon is made of paper, carbonized in a peculiar way, and afterward heated to a high temperature in a hydrocarbon vapor or gas. As is well known, carbon conductors, made by carbonizing paper in the ordinary way, have not proved commercially successful; they are extremely fragile; the structure of the carbon obtained is too porous and uneven for durability in use; and it is extremely difficult to secure uniformity of resistance. Mr. Maxim, however, has succeeded in overcoming the defects of the paper carbon, and the difficulties attending its manufacture. In carbonizing, according to his process, a stream of gas or vapor, rich in carbon, is passed through the muffle containing the blanks in process of carbonization, so as to envelop them on all sides during the time the muffle is in the furnace. Carbon from the gas is deposited in the pores and interstices of the material, very much in the same way as the deposit of carbon takes place in the ordinary gas retorts, and this greatly solidifies and improves the structure of the carbon conductor. The conductor is afterward heated to a high temperature by passing a current through it in a highly rarefied atmosphere of hydrocarbon gas, in order to still further improve its structure and standardize its resistance. Mr. Maxim has found that in this latter part of the process, very much better results are obtained by using a highly attenuated atmosphere of the gas, as an extremely high temperature can be used, and yet the deposition of carbon be carried on slowly enough to insure its penetrating the pores of the material. The deposit formed comparatively slowly, and at the same time at a very high temperature, is also of more even structure.

The application of this process to standardizing the resistance

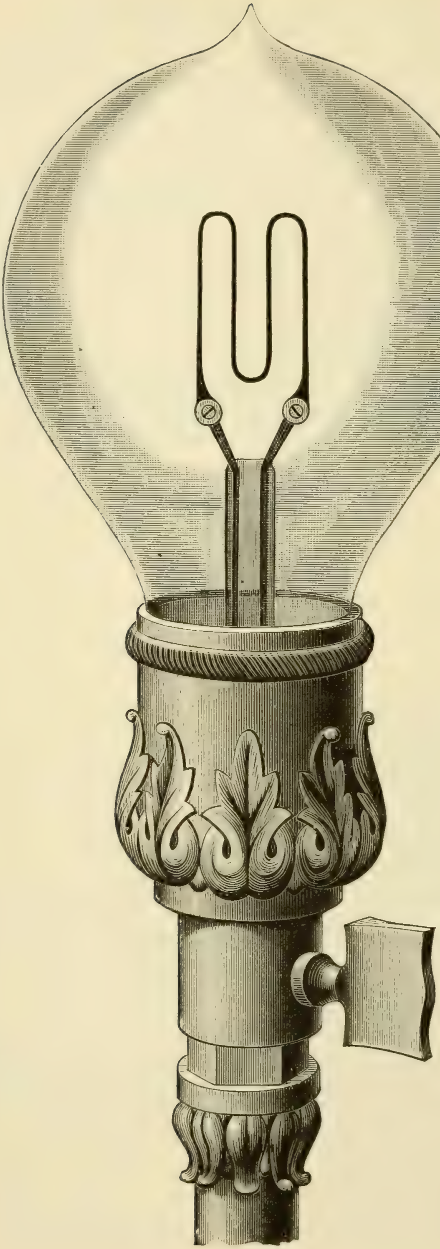

Fig. 124.

of the carbons is very ingenious. It is obviously of great importance, where lamps are run in multiple arc, that all the carbons should be, as nearly as possible, of the same size and of uniform resistance. It is very difficult to secure uniformity of resistance by carbonizing in the ordinary way, as the carbons produced from blanks of the same size and material differ widely in resistance. By Mr. Maxim's process all the carbons are made, in the first instance, of a resistance considerably higher than that desired, and they are afterward reduced to the standard. As the deposit formed by the hydrocarbon treatment increases the mass of the conductor, it correspondingly reduces its resistance, and the process of treatment is arrested with each carbon, when the standard resistance has been reached.

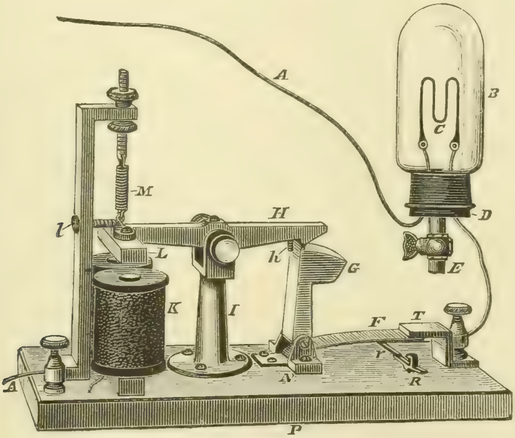

Fig. 125.

In Fig. 125 we show a device, designed by Mr. Maxim, for automatically cutting the carbon out of circuit at the proper time. An electro-magnet, *K*, is included in the same circuit with the carbon in course of treatment, which is represented at *C*. The surrounding vessel, *B*, contains a rarefied atmosphere of hydrocarbon gas. The wires *A A* lead to a generator which should be worked under the same conditions with all the carbons treated. It is obvious, that as the resistance of the carbon *C* decreases, owing to the deposition of carbon upon it, more current flows through the coils of the magnet; and the retractile spring *M* is so adjusted, that the magnet will draw down its armature when the resistance of the carbon has fallen to the standard fixed. When this occurs the hammer *G* is released, and, falling upon F, breaks the circuit suddenly at *T*, and cuts out the carbon; the spring *F* is prevented from rising again by a detent, *R*. In a modification of this device, which is somewhat more sensitive, instead of the retracting spring *M*, another electro-magnet, included in a derived circuit about the carbon in course of treatment, is made to pull down the other end of the armature lever *H*. By this apparatus the carbons are made of very uniform resistance.

The Maxim carbons have proved very efficient and durable. In reports of numerous experiments, made with the Maxim lamps at the Paris Exposition, and since, it is stated that lamps of the ordinary size have repeatedly been made to give a light of from 600 to 1,100 candles. This is a very severe test, and one which, so far as we have observed, has not yet been successfully endured by any other incandescent lamp. It would indicate a long lifetime for the lamps, when run at their normal lighting power, and this is, we are informed, the fact. From reports which have been received by the United States Company, from numerous plants which it has erected, the average lifetime of the lamp is shown to be considerably more than 1,500 hours. Lamps have, in numerous instances, lasted from three to four thousand hours; and we see no reason why this should not be made the average lifetime of the lamps when the processes of making them are still further improved. The present Maxim lamp has a resistance of seventy-five ohms cold, or about forty when in use.

As shown in the illustration, Fig. 124, the lamp is held in a socket or holder, which may be attached to an ordinary gas fixture, or other suitable support. The socket contains the terminals of the circuit leading to the lamp, and these are so arranged that the ends of the leading-in wires of the lamp are brought in contact with them when the lamp is inserted in the socket; and merely placing the lamp in position makes the necessary electrical connections.

Mr. Edward Weston has invented a new process of making carbons for incandescent lamps, which is, in some respects, quite a new departure.

The great desideratum for lighting by the incandescent system has been a more perfect form of carbon. With the extremely attenuated form of the luminous conductor in the modern incandescent lamp, serious difficulties, both mechanical and electrical, have been encountered, and very great difficulty has been experienced in securing the uniformity of calibre and density requisite for producing the same degree of incandescence throughout the whole length of the conductor.

Considerable difficulties have also been experienced in securing sufficient uniformity of quality in the material, and in working it into shape with sufficient accuracy. In two of the most successful of the incandescent lamps the fibrous structure of the carbon has been somewhat modified. In the Maxim lamp, although the basis of the carbon is structural in character, the subsequent treatment with hydrocarbon vapor fills up, in a great measure, the interstices between the fibres, and partially obliterates the structure. In the Swan carbon the structure is partially broken down, by the process known as parchmentization, before the material is carbonized. This obliteration of the structure is, in both cases, only partial; and the Maxim method appears to be preferable, as the treatment is so applied as to correct such inequalities of resistance as there may be in different parts of the conductor. In view of the advantages secured by this partial obliteration of structure, Mr. Weston was led to believe that still better results would be obtained if a carbon could be produced which should be entirely structureless. A high specific resistance is obviously very desirable; and, as carbons of vegetable origin appear to be of much higher specific resistance than those of inorganic origin, he directed his efforts to obtaining an entirely amorphous or structureless material of vegetable origin, out of which to form the carbon. This he has accomplished by entirely breaking down or obliterating the structure of cellulose, and reaggregating it in an amorphous form, but in such a way as to secure a very high degree of toughness and elasticity. The first method which he used for this purpose was to dissolve cellulose in ordinary form—such as cotton, linen or paper—with cupra ammonium, sulphuric acid, or some other efficient solvent, and thus obtain a gelatinous substance which could be formed into sheets or strips, and afterward carbonized. The substance thus obtained possesses nearly the same chemical characteristics as cellulose in the original form, but is amorphous, or without fibrous or cellular structure, and homogeneous. It is opaque and somewhat pliable, and the carbons formed from it, although homogeneous in structure, and much less brittle than carbons formed from inorganic substances, are not generally as elastic or strong as the carbons of the fibrous class. Very much better results were obtained by a somewhat different process, which he afterward adopted. Cellulose, in any of the ordinary fibrous forms, is subjected to the action of a mixture of nitric and sulphuric acid, in the same manner as in the ordinary processes for making pyroxyline, gun cotton or nitro cellulose, and this, when dissolved in a mixture of ether and alcohol, produces collodion, or by treating it with various other solvents—such as nitro benzole, naphtha or camphor, the ordinary celluloid is produced. Both collodion and celluloid may be shaped, with great facility, into any desired form, but so long as the characteristics of nitro cellulose remain they are not fit for the production of carbons, for the reason that they burn without any considerable residue, even in a vacuum, and accordingly will not carbonize. In order to render them suitable for this purpose they are deoxidized by treating them with such chemical agents as will deprive them of their nitrous qualities, and bring them back to the chemical constitution of cellulose. The best of such reducing agents are ammonium sulphydrate, protochloride of iron and sulphate of iron. In practice the celluloid or collodion is formed into thin sheets of somewhat greater thickness than that desired for the carbon conductors, and the sheets so formed are immersed in a solution of one of the deoxidizing agents, and allowed to remain in it until they are entirely reconverted to the original chemical condition of the cellulose. The product obtained by this process may be termed amorphous cellulose, and resembles closely, in many respects, ordinary celluloid, but differs greatly from it in others. When properly prepared it is almost entirely transparent, having only a slight amber tinge, is very tenacious and flexible, and may be readily carbonized in the ordinary manner, but the heat employed has to be somewhat greater than with ordinary fibrous materials. It is apparently entirely homogeneous, and, when examined under a microscope of very high power, it shows no structure. On account of its toughness, and the ease with which it can be shaped into any desired form, either by moulding during the process of manufacture, or by working with tools or dies after the process is completed, it will probably prove of great value for other uses than as a basis for electrical carbons; but for this use at least it appears to be the best material which has yet been devised. In making carbons from it, blanks or strips are cut or stamped out of sheets in the ordinary manner, and these are afterward placed in a retort and carbonized in the usual way. The material seems to work with dies and tools very much like a metal, and the outline of the blanks formed with dies is sharp and clear. The carbon resulting from the carbonization of this material is quite remarkable in its characteristics. It is apparently entirely homogeneous and amorphous; and, although the density of the carbon appears to be very great, its specific resistance is considerably higher than that of carbons prepared from fibrous materials, or those procured from inorganic substances. Owing to the great facility with which very thin sheets can be worked, and narrow blanks cut out of them, while still preserving great accuracy of mechanical work, conductors may be made of enormously high resistance. There appears to be no difficulty in making such conductors of three or four thousand ohms resistance, which show no unevenness of heating whatever under the influence of the current, and in securing sufficient uniformity of mass and resistance, in the different conductors, to dispense with subsequent treatment for standardizing. In appearance a carbon conductor made by this process closely resembles a fine steel spring, only the color is a lustrous black, and its elasticity and toughness are very remarkable. Conductors of ordinary size may be readily rolled into a spiral, about an ordinary lead pencil, without breaking, and when released, spring back immediately to their original form. With a conductor mounted in a lamp it seems to be absolutely impossible to break it by any mechanical shock or jar, even when the globe is shaken so as to cause the carbon to touch first one side of the globe and then the other. The extremely smooth and polished surface obtained appears to be an important advantage, as it materially reduces the attrition of any residual gases upon the surface of the conductor, and probably lessens the occlusion or adherence of air or gases. Although incandescent lamps, having conductors made by this method, have not yet been for a suffi-

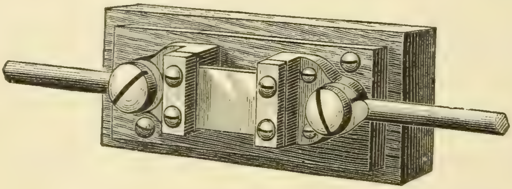

Fig. 126.

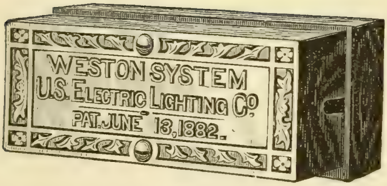

Fig. 127.

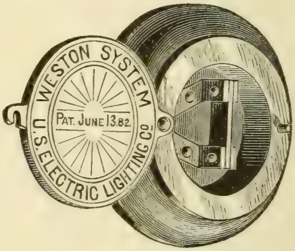

Fig. 128.

ciently long time in use to give precise results in regard to durability, it seems probable that this form of carbon will prove far superior, in this respect, to any other now in use; and we consider this an important contribution to the development of the incandescent system, especially if (as now seems probable) economy of distribution from large centres is to depend largely upon the production of efficient lamps of higher resistance than those now in use.

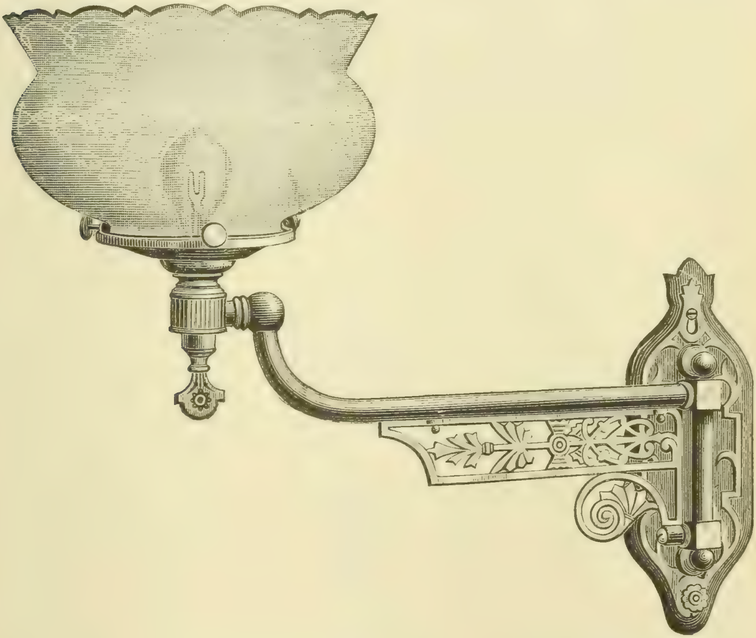

Fig. 129.

In Figs. 126, 127 and 128 are shown different forms of safety devices invented by Mr. Weston. With the multiple arc system, it is obvious that the distribution of the current among the branches depends upon their relative resistance. If from any accident one of the branches should happen to be short circuited, an abnormal amount of current would be diverted to it from the main circuit, and this might be sufficient to dangerously heat, or even fuse the branch wire. A safety device, of the form shown in the cuts, is introduced in each branch, to guard against this danger. It consists of a strip of easily fusible alloy introduced in the circuit, and arranged in convenient form for renewal. The alloy used is a compound of tin, lead, cadmium and bismuth, and fuses at about 155° Fahrenheit. The strip is made of sufficient size to convey the normal current without heating it to its fusing point; but in case of any abnormal flow of current, the alloy section of the branch would, of course, melt before the copper wire became dangerously heated, if the section of alloy were made of equal, or even somewhat greater conductivity than the rest of the circuit. As the fusing point of the alloy is below the point of ignition of any combustible, the drops of melted metal can do no harm in case the safety device is called into operation. These devices are made in various forms, some of which are shown in the cuts, and are located at any convenient place in the circuits, so as to be readily accessible for the renewal of the alloy strip when necessary.

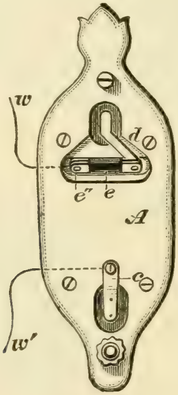

Fig. 130.

In figure 129 we show a form of bracket, devised by Mr. Weston, for incandescent lights. In figure 130 is shown a separate view of the wall plate A. The wall plate is permanently attached to the wall, and the circuit wires connected at *c* and *e''*. When the bracket is placed on the plate, its electrical terminals form contact with the springs *c* and *d*, and the wires pass from them through the fixture to the lamp. At *e*, in the wall plate, is a fusible cut-off. This bracket can be swung from side to side without affecting the circuit, as the connections are made through the pivots upon which it swings. Mr. Weston has also devised forms of double-swing brackets, drop-lights, chandeliers, and various other fixtures, for both arc and incandescent lights.

A plant has recently been erected at St. Denis, France, in which storage batteries are employed in connection with the Maxim incandescent and Weston arc lamps.

The installation comprises 10 Weston arc lamps, run directly from a Weston dynamo machine, and about 30 Maxim incandescent lamps, run from Kabath accumulators, which are charged during the day time by the same machine which runs the arc lamps in the evening. The works lighted are devoted principally to the construction of railway rolling stock, and include large stores of seasoned timber, saw mills, and paint shops, which, more than most other work shops, demand constant watchfulness to avoid fire. For this reason, lighting by gas or by oil involves many dangers, while the electric light, properly carried out, is quite safe. The engine at the works does not develop more than about 60 effective horse-power, of which 48 are absorbed by the various machines, tools, etc., leaving only about 12 horse-power available for electric lighting purposes. This the company desired to utilize to the maximum; but running lights directly from the machine, it would not suffice for more than about 10 arc lamps.

During four hours each day, the Weston generator is employed in charging 80 accumulators of the Kabath corrugated type, placed about 250 yards from the generator, and connected to it by insulated conductors, arranged overhead. These accumulators, arranged in two series of 40 each, have sufficient capacity to supply, during the period of lighting, each day (about three hours) the current necessary for feeding 30 Maxim incandescent lamps, distributed over the painting shops and drying sheds. The brushes of the Weston machine can be readily shifted on the commutator, so as to vary the strength of current within certain limits; but for charging the accumulators as arranged, it was found necessary to diminish it still further, and to adopt an arrangement by which the current could be shifted directly from the lamps to the batteries, and back again, without endangering one or the other. For this purpose, an iron wire resistance is introduced into the charging circuit, so that the electro-motive force may be diminished, and in the same circuit is placed an automatic circuit breaker to guard against reversal of polarity of the machine.

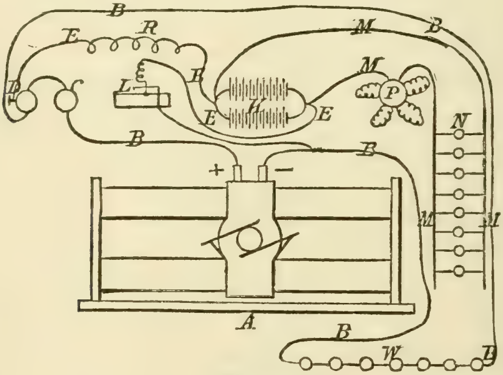

Fig. 131.

In charging accumulators with a dynamo-electric machine, if the counter electro-motive force of the accumulators should become higher than the electro-motive force developed by the generator, the accumulators would commence discharging through the machine, and reverse the polarity of the field magnets. This would be especially liable to occur, when the machine is started, and a reversal of the charging current would be disastrous to the accumulators. For the purpose of preventing such back-flow of current from the accumulators, an automatic switch is used, which opens the discharging circuit in case of any back-flow of current. Fig. 131 is a diagram, showing the general arrangement of the machine, arc lamps, accumulators, and incandescent lamps. *A* is the dynamo machine; *B B* the circuit for the arc lamps, which are indicated by *W*; *C* is a galvanometer; and *D* a two-way switch, both of which are included in the main circuit.

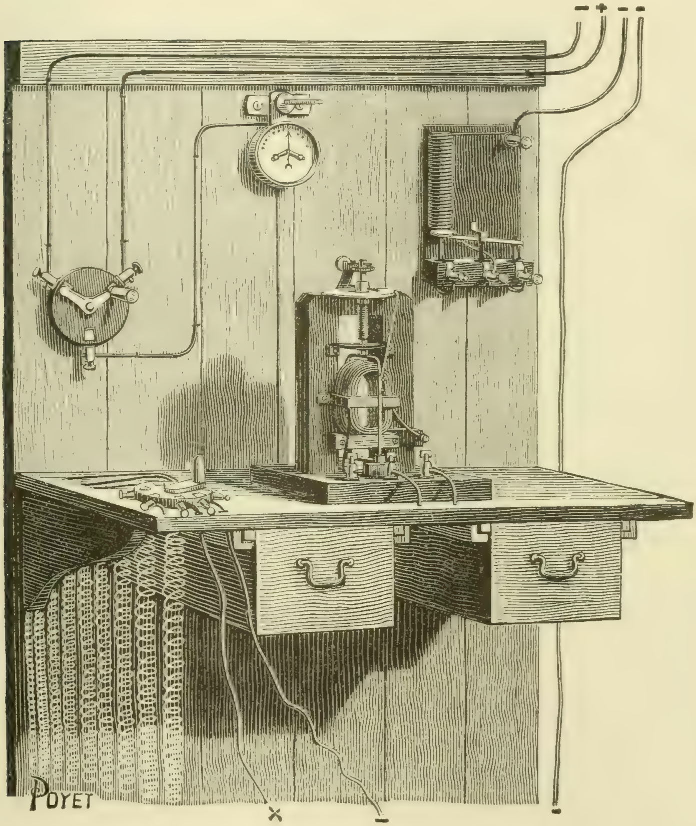

Fig. **132.**

During the day time, the switch *D* is set, so as to connect the generator with the circuit *EE*, which includes the Kabath accumulators *K*, the resistance *R*, and the automatic circuit breaker *L*. At night the switch is set so as to connect the generator directly with the arc light circuit. The terminals of the two series of accumulators are also connected to the circuit *M*, which includes the Maxim incandescent lamps *N*, arranged in multiple arc; and a fourteen-way commutator *I*, the plates of which are connected to resistance coils of iron wire, so as to permit the resistance of the circuit to be gradually reduced as the batteries run down, and the strength of the current in the incandescent lamps to be maintained constant by hand regulation. The regulating apparatus and circuit shifting devices are illustrated in Fig. 132.

The ten arc lamps are used for lighting the saw mill, which is 495 feet long, 114 feet 9 inches wide, and 88 feet high. The lamps are placed at a height of 20 feet from the floor. The Maxim incandescent lamps are used for lighting the paint shop, which is 344 feet long, 55 feet 9 inches wide, and 39 feet high. The arrangement used for supporting these lamps is somewhat peculiar, and seems to afford considerable advantages for the purposes for which the light is required. As it is necessary to illuminate the cars in course of construction, and variably, according to the progress of the work upon them, it is necessary to be able to shift the lamps at will, and to place them where the light is especially required. To allow this to be done, the lamps are suspended as shown in Fig. 133. Four parallel pairs of stout uninsulated copper wires are stretched horizontally across the room at a convenient height, and the lamps are mounted upon movable fixtures, which rest upon these conductors. The fixture for each lamp consists of a piece of tubing, enclosing two insulated wires leading to the terminals of the lamp, and terminating at the upper end in two copper arms, which are so arranged as to form contact with the horizontal supporting wires, the whole fixture having the shape of a greatly elongated T. These horizontal wires are connected with the circuit of the accumulators, so that they form conductors leading to the different fixtures supported by them. Good contact between the horizontal wires and the arms of the fixtures is insured by occasionally rubbing the conductors with emery cloth. With this arrangement, the lamps may be shifted at will along the horizontal conductors; and, as these conductors are arranged between the tracks on which the cars stand, the lamps may be placed in any desired position for properly lighting the work in progress.

This plant has not yet been in operation for a sufficient time to furnish exact data as to the cost of lighting, and the advantages it offers, in point of economy, as compared with gas lighting of equal intensity. Certain information on this point, though somewhat hypothetical, is available; but it is clear that the system is greatly superior to lighting by gas as regards security from fire, a matter of very great importance in a factory containing large quantities of inflammable material.

As we have already stated, the power available for lighting purposes does not exceed 12 horse-power, and in this case it costs practically nothing, the additional work of driving the generator adding nothing to the men's wages, and nothing appreciable to the cost of fuel, which consists almost wholly of wood rubbish. A workman who is paid $1.20 per day has charge of the plant; but, as only about half his time is occupied on this work, the item of attendance may be put down at 60 cents per day. The Weston arc lamps each use two carbons, .43 of an inch in diameter, one 19 inches long and the other 8 inches, which last during six hours' burning. These carbons cost 11 cents per foot, and the hourly expense for carbons is accordingly about four cents for each lamp, or about $1.20 for the 10 lamps for three hours, including waste. The Maxim lamps cost $1.94 each, and last for about 1,000 hours; equivalent to an expense for renewals, of two mills per hour per lamp, or 18 cents for the 30 lamps, running three hours per day. This part of the lighting will, therefore, cost as follows:

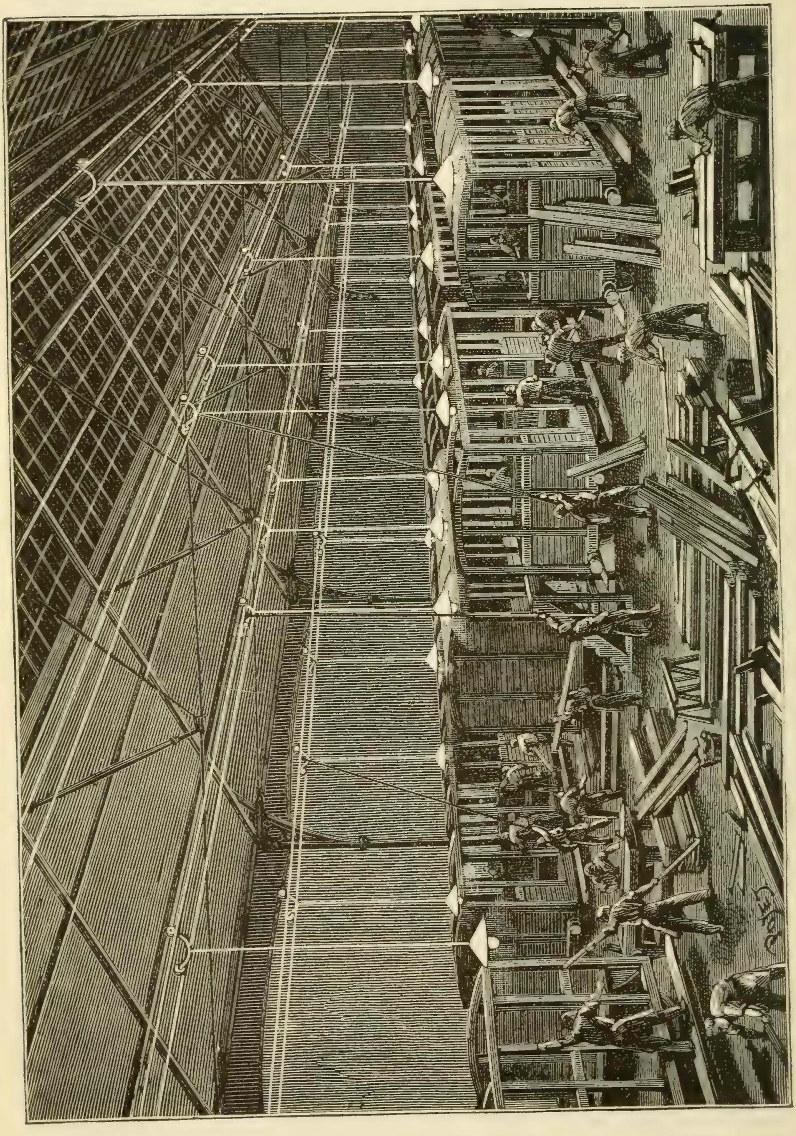

Fig. 133.

Attendance	$0.60
Carbons	1.20
Renewals of Maxim lamps	.18
Total	$1.98

The cost of the acidulated water used in the accumulators, which contains ten per cent. of sulphuric acid, is insignificant. The cost of the installation was $3,600, and taking interest at 5 per cent., and depreciation at 5 per cent., about 56 cents per hour would have to be added for these items, bringing up the total cost to $2.54. It should be borne in mind, however, that no allowance is made in this case for the cost of power, as these figures are based on the assumption that the power costs nothing.

While it is certain that the Weston machine is so well designed and constructed that its wear is of very small moment, the sum allowed for repairs of the accumulators is, in the absolute data, as low as can be safely assumed. It should be mentioned, however, that Mr. de Kabath undertakes to replace the batteries for nothing as they are worn out, relying upon making a profit on the sulphate of lead produced. Assuming that all the running expenses do not exceed the above figure, a light equal to 1,000 carcels is obtained from the Weston arc lamps, and of 90 carcels from the Maxim incandescent lamps. The cost of gas, to produce the same amount of light, at Paris, would be about $3.54 an hour.

In an installation of the kind we have described, and assuming that the power costs nothing, it is not necessary that the duration of lighting should be nearly 1,000 hours per annum, to make the comparison of cost favorable to lighting by electricity. Down to 220 hours per annum there is a saving in using electric light, over Paris gas, and at that point the charges for the two are equal.

The arrangement adopted in this plant can probably be greatly improved in the erection of other plants of the same type. The use of the resistances, either in the charging circuit or for regulating the discharge of the accumulators, is not to be commended; and much better results would be produced, by using a larger number of accumulators and grouping them differently, so as to utilize the entire charging current and by regulating the discharge of the accumulators by varying the number of cells. It is only fair to say, however, that Mr. Farquhar, the engineer who had charge of erecting the plant, sought to secure simplicity first of all, and he has succeeded very well. With additions to the number of incandescent lamps and accumulators, better results will be obtained.

THE SWAN INCANDESCENT LAMP.

Mr. J. W. Swan, of Newcastle-on-Tyne, England, has discovered a method of preparing from cotton-thread very attenuated filaments of carbon of the tenacity requisite for their sufficiently prolonged stability and endurance when employed as an incandescent lamp. These extremely thin carbons are perfectly homogeneous throughout, and are so far from becoming damaged by use that the effect is to a certain extent an increase of their solidity and elasticity.

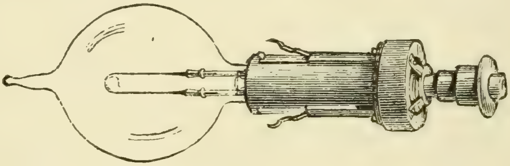

Fig. 134.

We represent, in Fig. 134, a Swan lamp with its mounting shown at the Paris Electrical Exhibition, which allows of its very easy introduction into the bracket or chandelier which is to support it. It consists of a glass sphere, into which are introduced two platinum carbon-holders having clasps and pressure ring precisely like porte-crayons that were once in use. The carbon filament, which is much larger at its extremities, that are grasped by the holder, is bent into a flat helix in such a way as to form a ring in the middle of the sphere and to accumulate at the centre of the latter a greater quantity of light.

The preparation of these carbon filaments is a little different from that of the Edison carbons. They are made of threads or tresses of cotton about 4 inches in length, whose extremities are enlarged by a local winding of the material. These threads are dipped into sulphuric acid diluted with water, in the proportion of two parts of the former to one of the latter—the result of this operation being to parchment them. Under such conditions, and after a certain length of time, the threads become consistent and as hard as parchment. They are then introduced into powdered carbon contained in an earthen vessel, which is afterwards hermetically closed and submitted to a red heat for a certain length of time. After this they are placed in the lamps, and, when a vacuum has been created in the latter by means of the Sprengel pump, the precaution is taken to bring them electrically to incandescence, so as to eliminate all the gases which might possibly exist in their pores. After this operation, which may take half an hour, the filament has become very hard, and at the same time denser and smaller. It is in this state that it becomes suitable for application. The resistance of these filaments varies between 30 and 100 ohms, and the light that they emit under ordinary conditions varies, according to Mr. Swan, between 12 and 25 candles. In order to avoid calorific effects at the points where the carbon-holders are soldered in the glass, the holders are made to advance into the globes for some little distance, and are held by a glass cross-piece. The platinum wires to which they are soldered communicate with two flat springs (as seen in Fig. 134) on the two sides of the mounting, and in order to introduce the lamp into its support, or to remove it, it is only necessary to press on these springs and afterwards release them; the electrical communications are established by this sole act.

Fig. 135 shows the way in which Mr. Swan has adapted his lamp to a portable support forming a chandelier, and Fig.

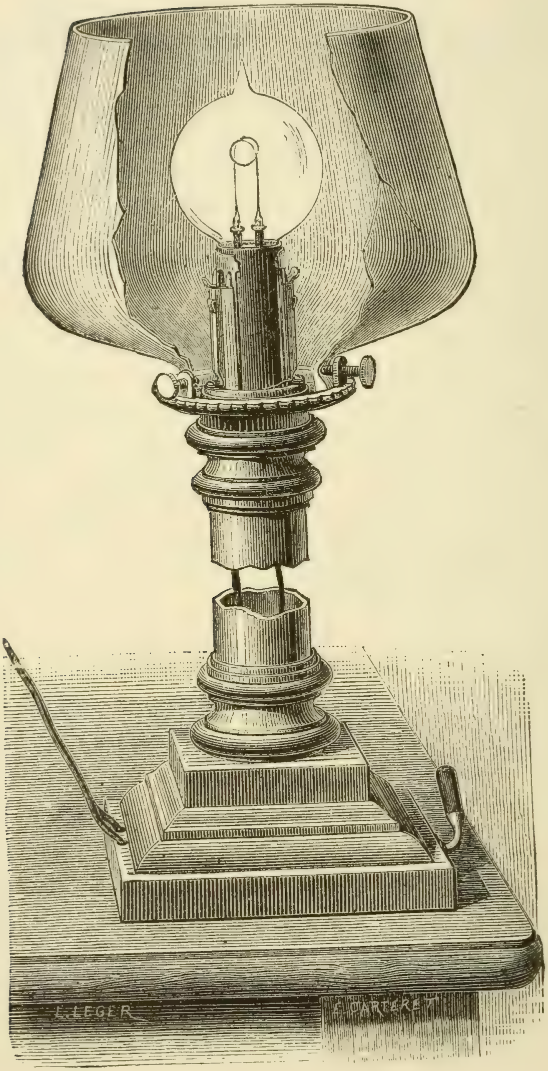

Fig. 135.

136 represents the bottom of the chandelier, and permits of the electric communications being seen.

Fig. 137 shows Mr. Swan's lamp for lighting the galleries of mines.

At a meeting of the Society of Telegraph Engineers, in London, November 24, 1880, Mr. Swan gave the following interesting account of the origin of his lamp:

Electric lighting by means of the arc, and by the incandescence of thin abutting carbon rods, has recently been discussed in an exhaustive manner at two of your meetings. The one other mode of electric lighting besides the two I have mentioned, namely, by the white heat of a continuous conductor, was barely glanced at in these discussions. This method of electric lighting is, however, theoretically so good, that, supposing the practical difficulties which surround it can be surmounted, it instantly assumes a position of importance far above that of the methods upon which you have so recently bestowed exclusive attention.

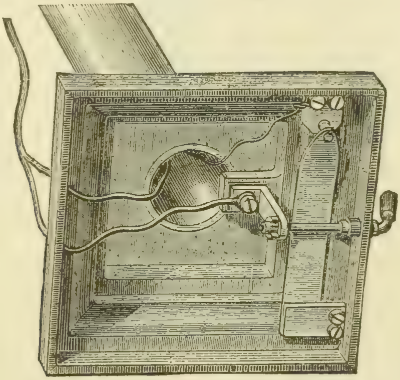

Fig. 136.

Everybody in the least acquainted with the subject knows, that if we exclude from consideration this last named method, lighting by means of electricity has an extremely limited range of application.

Electric light, as produced by the arc, in foci of great luminosity, is unquestionably an economical light when concentration of light is advantageous, but even then, the mechanism necessary to counteract its tendency to vary in power, the noise which is apt to accompany it, the trouble and cost of the replacement of the carbons, are inherent defects of such magnitude as must always greatly diminish, and frequently entirely neutralize, the advantages of its economy and extreme brilliance.

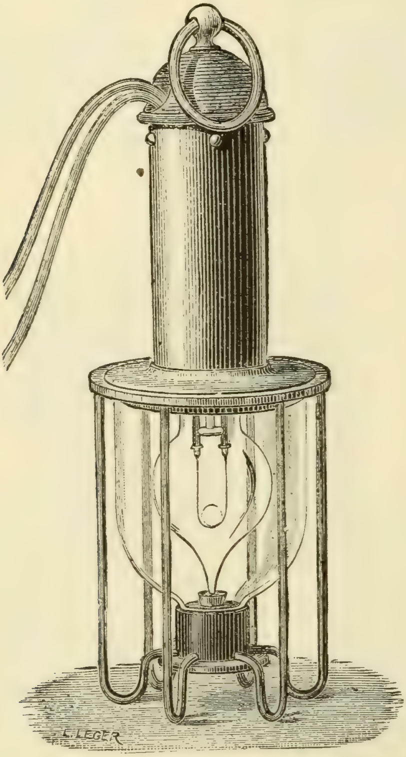

Fig. 137.

Where concentrated and powerful light is inadmissible, and an equable distribution of light by means of small light centres is required, there the electric arc is totally inapplicable. It is impossible by that means to produce economically such a small unit of light as in nine cases out of ten, or even in ninety-nine cases out of a hundred, is required for practical use. The moment you attempt to produce a small arc light you sacrifice its chief redeeming quality, namely, its economy.

In those cases where the arc light on a large scale for lighting large spaces is not inapplicable, much of the economy of the light, considered merely with reference to its aggregate amount, is lost by the diminished power of the light at the extreme margin of the area of illumination.

It is not so much the power of the light at its focus that has in most cases to be considered, as the amount of light at the least illuminated points of the space illuminated. Just as we say the strength of a chain is its weakest link, so we may as truly say, that where the general illumination of a certain area is in question, the value of a particular mode of lighting must be measured by the amount of light at the points of least illumination. Whether we agree or not as to the ratio of loss in subdividing the arc light, I am certain that the opinion I have already expressed will not seriously be contested by any one here, namely, that when you come below a rather large unit of light, you cannot subdivide the arc without great loss. Looking at the matter from this point of view, it appears to me that the only direction in which we can move with any chance of substantial progress toward the making electric illumination generally applicable, is the direction I have taken, namely, that of abandoning the arc altogether, and going to incandescence pure and simple. On the principle of incandescence, and on that principle alone, you can produce with economy such a small unit of light as is required for domestic use and general purposes. On the principle of incandescence alone, can you economically divide electric light, and on that principle you can divide it indefinitely. By means of incandescence it is possible to produce a single light, say of 100 candle power; and with precisely the same expenditure of energy, the same aggregate amount of light may be produced in, say ten separate places.

Being in your meeting-room at Broad Sanctuary with a few minutes on my hands, I took the liberty of taking a volume from one of the shelves of your most excellent library; it was the first volume of Faraday's Experimental Researches in Electricity. I first turned to the index and then to page 250, and there I read this: "The same quantity of electricity which, passed in a given time, can heat one inch of platinum wire, of a certain diameter, red hot, can also heat a hundred, a thousand, or any length of the same wire to the same degree, provided the cooling circumstances are the same for every part in all cases."

Speaking, as I do, to electrical engineers, who have the bearings of Ohm's law at their finger ends, it is not necessary to elaborate this point. You, of course, all recognize the fact that a specific degree of incandescence produced in a certain wire by the transmission of an electric current is indicative of a specific current flow, and whether a short piece of the wire is heated to the supposed degree, or a long piece, the same current flow will be required in both cases; and, other circumstances being alike, whether one inch is heated, or one hundred inches, the only condition necessary to be observed in order to the maintenance of a constant current, and consequent constancy of incandescence in the wire, is variation of the electro-motive force exactly as the length of the wire varies.

I may therefore say, in strict accordance with theory, that the indefinite division of electric light produced on the principle of the incandescence of a resisting and refractory conductor is unattended with loss. The only question is, the all-important one of the practical realization of that which theory says is possible.

It is undeniable that great practical difficulties attend the economical application of the principle of incandescence. Platinum, iridio-platinum, and carbon are the chief substances available for producing light on this principle with which attempts have been made. The difficulty with platinum and with iridio-platinum is, that they fuse or break before they attain a temperature of economical incandescence; and when it is remembered that after a certain degree of incandescence is attained, increase of current produces much more than a corresponding increase of light, it will be evident that it is vital to the economy of this mode of lighting to be able to heat the incandescent body to a very high degree. Mr. Edison has stated that by frequently heating and cooling a platinum wire in vacuo, it sustains a very much higher temperature without fusion (perhaps it would be more strictly accurate to say, without rupture) than when not so treated. Notwithstanding this improvement in the adaptation of platinum to incandescence lamps, and notwithstanding also some very ingenious contrivances to guard against fusion of the wire, I think, perhaps, one is warranted in the assumption, that the abandonment of this form of lamp, and the taking up with carbon instead of platinum, is an acknowledgment of its non success.

Carbon has been more attractive to experimenters in this field of research than platinum, and a much more tangible result has been attained by its mediation.

Since 1845, when King proposed to produce electric light by means of a continuous carbon conductor intensely heated by the passage of a current of electricity, there have been numerous attempts to realize a useful form of electric light by means of white-hot carbon.

It is needless to say that, in order to make the carbon in an incandescent lamp give forth a useful amount of light, it must be made very hot, so hot that it would immediately burn if there were air present. There are lamps, generally called incandescence lamps, in which no precaution is taken to prevent combustion; such are the Werdermann, Reynier, and Andre lamps. These lamps ought not to be classed as incandescence lamps in the sense in which alone I use that term, viz., to describe lamps in which there is white heat without combustion. No extensive economical subdivision of the light by lamps in which there is combustion is to be hoped for. The true incandescence lamps prevent the combustion of the carbon in one of two ways, either by the entire exhaustion of the air from the chamber in which the heated carbon is placed, or by the filling of the chamber with an inert gas, such as nitrogen. Both these expedients were tried by the early experimenters, and both have still their advocates.

Many of the older attempts to utilize carbon as the medium of incandescence, for a time, appeared to be successful; but eventually they disappointed the hopes they had raised at the outset. They failed from three causes, any one of which was sufficient to cause failure. First, the carbons employed were so thick as to require a large current to produce the required temperature in them, and consequently the light was not economical; second, the carbons were not durable; and, third, the lamp glass speedily became obscured. It is long since I attempted to grapple with the first of these difficulties.

As a matter of history, I will briefly describe an experiment which I tried about 20 years ago. I had a number of pieces of paper and card of various forms and sizes buried in charcoal in a crucible. This crucible I sent to be heated white-hot in one of the pottery kilns belonging to Mr. Wallace, of Forth Banks, Newcastle. From the pieces of carbonized card which I thus obtained, I selected a long spiral; the ends of this I clipped between small blocks of carbon carried by uprights and connected with conducting wires. A small glass shade was cemented over this mounted carbon spiral, and the air was exhausted by means of a very good air-pump. A good vacuum (according to the ideas that then prevailed) having been produced, I applied the wires of my battery (consisting of 10 cells of Callan's modification of Grove's battery), with great expectation of a brilliant result; instead of this there was the most absolute negative presented to me; not a vestige of heat or light appeared in my long ringlet of carbonized paper. It was evident, and I immediately recognized the fact, that the electric current of the strength I was using would not go in sufficient quantity through so long a piece of carbon as I had taken. I therefore repeated the experiment with shorter carbon and a greater number of cells, and I obtained, under these altered circumstances, an extremely interesting result.

My carbon was in the form of an arch about one inch in height and width, and the strip forming the arch a quarter of an inch broad. The ends of the arch were held in small clamps, with square blocks of carbon.

The air pump having been worked, I had the pleasure of seeing that when contact with the battery of 40 or 50 cells was completed, my carbonized paper arch became red hot, and it was evident that nothing more was wanted than a still stronger current to make it give out a brilliant light; but I had used all the battery power at my disposal, and having reached this limit, I contented myself with watching the behavior of the arch, the engrossing question being—how long will it endure? I noticed that the inner part of the arch was hotter than the outer part, and that, perhaps in consequence of this, the arch became bent on one side. This bending gradually increased, until at last the arch had so far curled down that the top was on a level with the clamps, and on coming in contact with the sole of the lamp it broke in two, and the experiment collapsed.

That, I confidently believe, was the very first instance in which carbonized paper was ever used in the construction of an incandescent carbon lamp. I am now speaking of twenty years ago, and at that time the voltaic battery was the cheapest source of electricity known, and the means of producing high vacua were very much less perfect than they are now.

I laid my electric experiments aside until about three years ago, when two things concurred to lead me to pursue the subject afresh. The discovery of the dynamo-electric machine had entirely altered the position of the question of electric lighting, shifting it out of the region of things scientifically interesting into that of things practically useful. The Sprengel air-pump, too, had been invented, and with its invention we had been provided with a means of producing much higher vacua than could be produced by the old form of air-pump. Mr. Crook's radiometer experiments had shown us what a really high vacuum was, and how to produce it. Mr. Stearn, of Birkenhead, an ardent scientific amateur, was so attracted by the extraordinary results Mr. Crookes had obtained by means of high vacua, as to go with great enthusiasm into the same line of experiment, and he soon acquired such a knowledge of the Sprengel pump, and such expertness in its manipulation, as perhaps was only equalled by Mr. Crookes himself. I had the good fortune to make Mr. Stearn's acquaintance, and that was the other one of the determining causes of my second attempt to solve the problem of electric lighting by the incandescence of carbon, for it is to the invention of the Sprengel pump and to the many admirable lessons in the use of it which Mr. Crookes has given us that we are indebted for the means we now possess of attaining to the condition essential to the successful employment, in electric lamps, of thin strips or filaments of carbon.

But if the employment of carbonized paper got rid of the difficulty as to the waste of current due to the thickness of the carbon, there still remained the other two difficulties, viz., the tendency of the carbon to disintegrate and break and the obscuration of the globe. How formidable those difficulties are may be judged of by the following extract from Fontaine's well known treatise on electric lighting, in which he gives us the results of his experiments in the production of light by incandescence.

At page 180 this passage occurs: "Attentive examination of incandescent carbons through a strongly-colored glass has shown that they are not uniformly brilliant; they present obscure spots, indicative of non-homogeneity and the position of cracks, which rapidly disintegrate the carbon. The vacuum never being perfect in the receivers, the first carbon is in greater part consumed. It would appear that consequently upon the little oxygen contained in the lamp being transformed into carbonic acid and carbonic oxide, the carbon should be preserved indefinitely; but there is then produced a kind of evaporation which continues to slowly destroy the incandescent rods. This evaporation is, besides, clearly proved by a pulverulent deposit of sublimed carbon that we have found on the interior surface of the bells on the several interior parts, rods, contacts, hammers, &c."

It never seemed to me conclusively proved that M. Fontaine's theory of the breaking of the carbons and the obscuration of the globes was correct, and I did not accept it. I remembered, for instance, how impossible Mr. Crookes had found it to produce a really high vacuum in vessels with luted joints, and I knew how commonly luted screw joints had been used in the fittings of incandescent lamps. I knew too that the common air-pump had generally been employed as the means of exhausting the air. Then, too, the mode of attachment of the carbon to the conductors conveying the current to it had been such as must inevitably lead to excessive local heating, and even to the occurrence of disruptive discharge about the points of attachment.

Watching the course of events in relation to electric lighting experiments, and observing the very imperfect conditions under which generally those experiments were conducted—and that full advantage had not been taken of the new powers which the progress of scientific research had placed within our reach—I three years ago returned to the quest with the distinct purpose of finding whether or not carbon made from carbonized card, and carbonized paper, were durable in a really high vacuum, such as Mr. Crookes had employed in his experiments on the radiometer. This time I had, as I have mentioned, the great advantage of the assistance of Mr. Stearn, of Birkenhead, who in addition to being exceedingly expert in the manipulation of the Sprengel air-pump, is an admirable experimentalist generally. Since then experiments without number have been made by us with the view of surmounting the various practical difficulties of which I have spoken, chiefly the breaking of the carbons when made highly incandescent, and the blackening of the globes. Tolerably good results were obtained with carbonized paper and carbonized card-board, but latterly I have found a material (a form of carbon) which is very much better suited to the purpose. With this new material the lamps which I am about to exhibit to-night are fitted.

Here is one of my carbons. It is, you will observe, an extremely thin carbon wire about .01 of an inch in diameter, and weighs about the .02 of a grain to the inch. It is both hard and elastic, so much so, as more to resemble a fine steel wire than carbon. Its hardness and non-combustibility increase with lengthened use. After being used some time it becomes so difficult of combustion as to bear heating in a blow-pipe flame for a considerable time before it burns away.

I am able to shape this carbon wire into circles or spirals or almost any form, and to thicken the ends so as to make a good and extensive contact with the holding sockets. A current of less than a Weber going through this carbon wire raises it to a state of brilliant incandescence, and if the current much exceeds that amount then the light becomes splendid. I have not yet finally ascertained what is the greatest amount of light that, with sufficient regard to durability, can be obtained by means of one of those spirals of not more than one-tenth of an inch total superficial area. I have taken a few photometric measurements, 60 candle-power from one lamp being the greatest amount of light actually measured; that degree of luminosity was produced with about one Weber of current, and 100 volts E.M.F. I have seen at least double this light from each lamp. At Sir William Armstrong's, at Cragside, there were sixteen lamps hanging in the picture gallery. The current from a large Siemens machine was divided between these and a resistance coil. For a minute or two the resistance coil was cut out by short circuiting, then the short circuit contact was broken and the resistance coil left out, so that the full current from the generator, the potential raised to a very high degree by the short circuiting, rushed in a torrent through the sixteen lamps; there then occurred the most glorious outburst of light I ever beheld. It was truly splendid! It lasted I should say full five minutes, and then subsided to normal brilliance.

The economy of this method of producing electric light by the incandescence of carbon in vacuo is limited by the capacity of the slender conductor to endure the enormously high temperature corresponding to an extreme degree of incandescence. It is certain that the carbons are more durable when heated to a moderate degree than when their temperature is pushed to an extremely high point. It is, therefore, still an open question what is the most light that can be practically obtained by means of such lamps. We do however know this, that a well made lamp of this size will endure for several months if it be not pressed to give more than the light of 30 standard candles. It is quite likely when the manufacture is improved, as it will be by practice, that twice this amount of light may be exacted without too much limiting its durability.

The vacuum in the lamps is very high—in fact it is carried to that point at which it is practically non-conducting.

The lamps which are hung about the theatre are arranged in parallel arc. I have elsewhere expressed the opinion, that with the lamps so arranged the current cannot be economically supplied at a great distance from the generator: to accomplish that end and render it feasible for current supply to be sent from a centre over a wide area, as gas through mains, it will, I think, be necessary to use a very high electro-motive force and arrange the lamps in series. The difficulties which are incident to that method are, I hope, not insuperable; extinction of a line of lamps, from the failure of one of the lamps of the series, could be guarded against by a very simple form of automatic by-way, and the potential of the current could be made to rise or fall correspondingly with a variation of the resistance, and so as to maintain a constant current, however few or however many lamps were lighted.

The resistance of the lamps obviously depends on the length and thickness of the carbon wire. Those I have spoken of as emitting, when moderately heated, a light equal to 30 standard candles, have a resistance of about 100 ohms when cold. I have made them of twice that resistance, but even then it would be impossible to feed at a distance a large group of lamps arranged in parallel arc with a small conducting wire.

I have said nothing about cost, beyond giving you one or two facts, which will afford you the basis of an approximately correct computation, and from which it will appear that while, by the incandescence of thin conductors of carbon, a certain current does not give so large a return in light as when employed to produce the electric arc between carbon points on a large scale, yet the amount of light developed by a given expenditure of power is amply sufficient to warrant the statement that it is an economical source of light.

The most recent form of the Swan lamp is shown in Fig. 138. The exterior of the lamp is entirely of glass. The wires which hold the ends of the carbon, and are fused into the glass, are bent into hooks for engagement with other hooks forming the terminals of the circuit wires, the lamp being pressed downward, so as to bring the hooks into engagement by the spiral spring into which its neck is inserted.

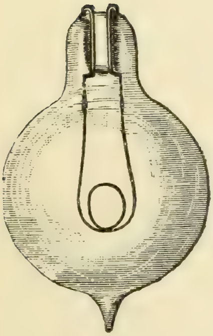

Fig. 138.

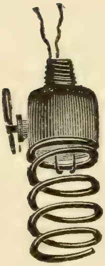

Fig. 139.

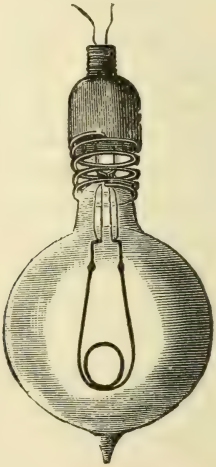

Fig. 140.

The lamp connection is shown in Fig. 139, and is simply an ebonite stud with a plug screw for attachment to a gas bracket or other support. On each side of the stud are two small platinum hooks projecting downwards.

Figs. 140 and 141 show the Swan lamp complete, and ready

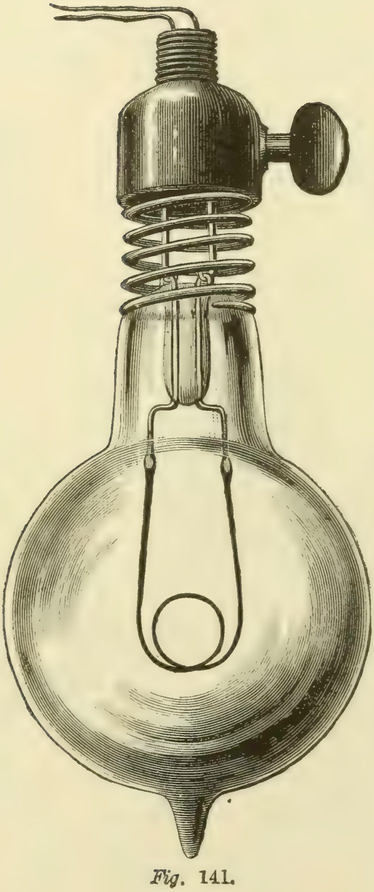

Fig. 141.

to be screwed into its support. Figure 142 shows the Swan ship lamp. Figure 143 shows a form of bracket lamp, and figure 144 a table lamp.

Figure 145 shows an arrangement of the Swan ship lamp adjusted to oil fixtures, and figure 146 an ornamental specimen electrolier.

As to the durability of the Swan lamp, we are informed that in the Savoy Theatre, London, which is illuminated by them (the current being supplied by a dynamo), the lamps have lasted 3,000 hours. This is due, in a great measure, to the homogeneity and density of the carbon filament, and the perfect uniformity in its size and shape from end to end.

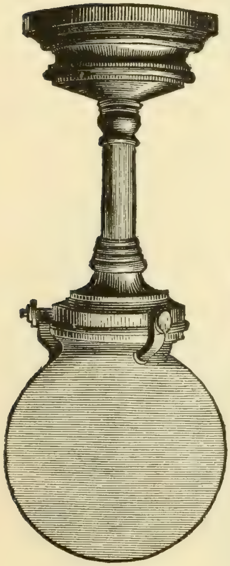

Fig. 142.

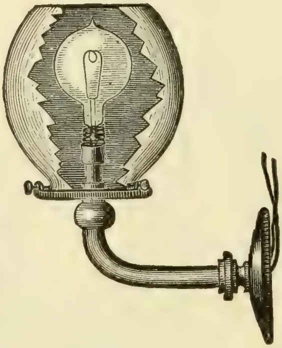

Fig. 143.

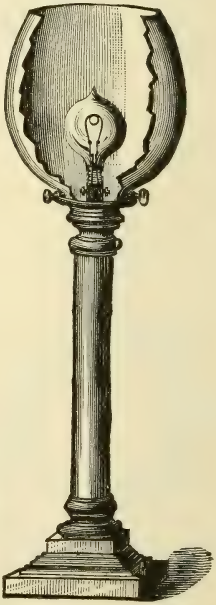

Fig. 144.

A private exhibition of the Swan incandescent electric light was recently given at the offices of the Brush Electric Light Company, in New York, in connection with the Brush storage battery, and the Brush current manipulator. These devices—located on the premises of every consumer—in connection with the distributing wires of the street system and generating dynamos of the district, constitute the Brush Swan system for electric lighting by incandescence. The current may be taken from the arc lamp circuit during the evening, while the arc lights are in operation, or in the day time while the lamps are cut out of

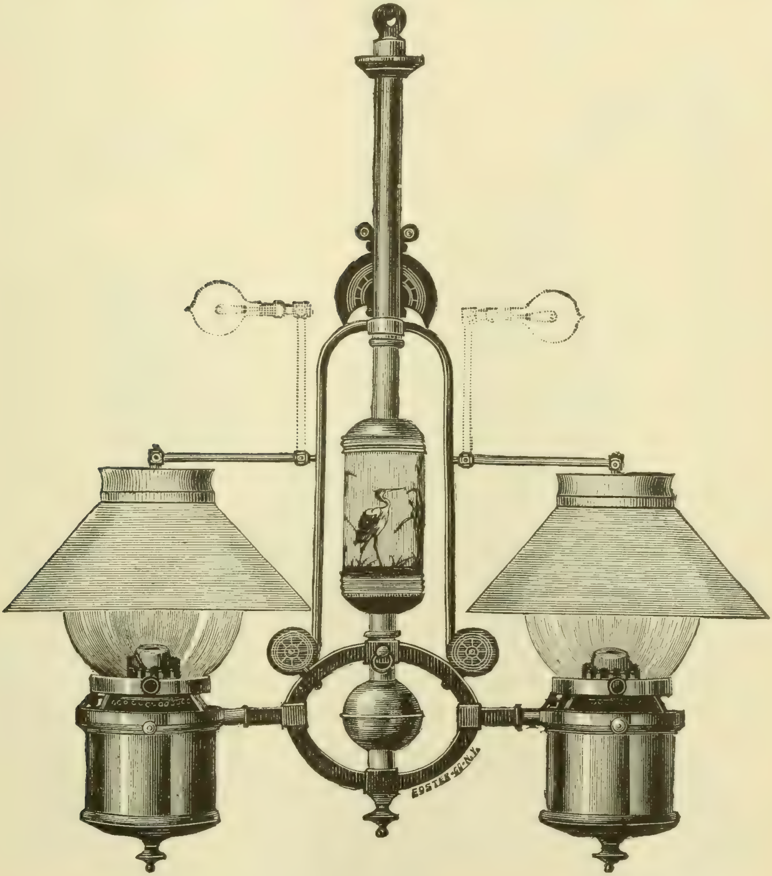
EOSTER-CO-N.Y.

Fig. 145.

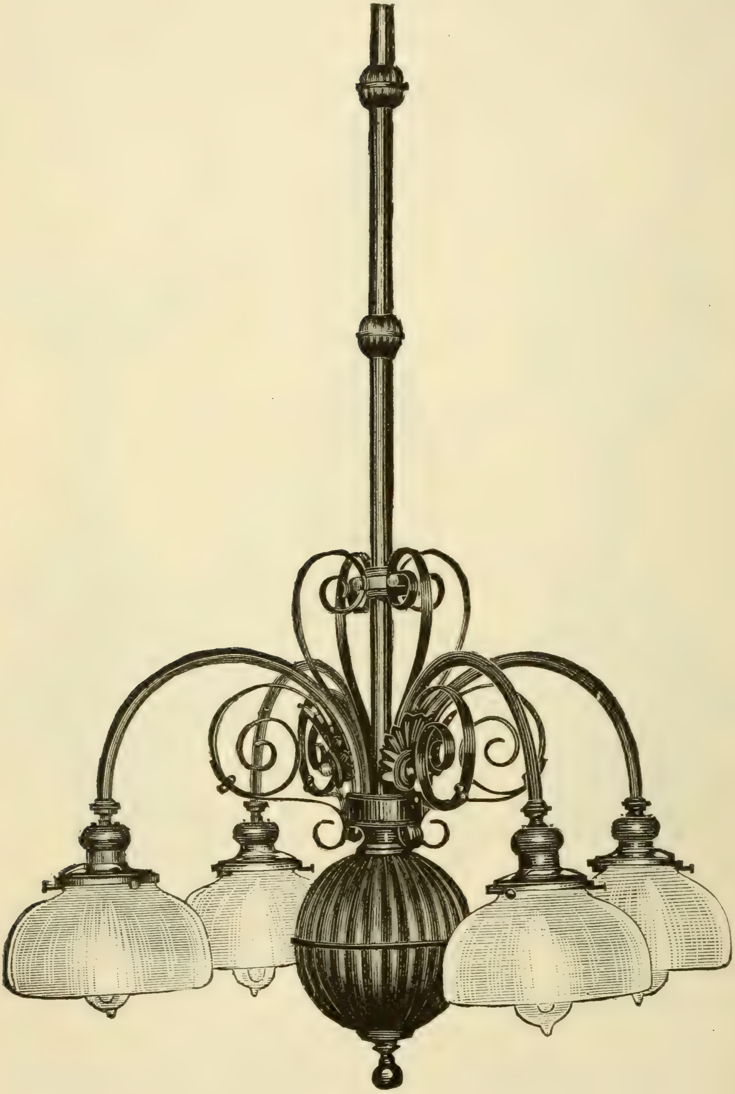

Fig. 146.

the circuit, or they may be placed in a special circuit and charged by machines set apart for this use alone. The important features of the system are: first, to provide an unfailing supply of electrical energy, by the use of the storage batteries:

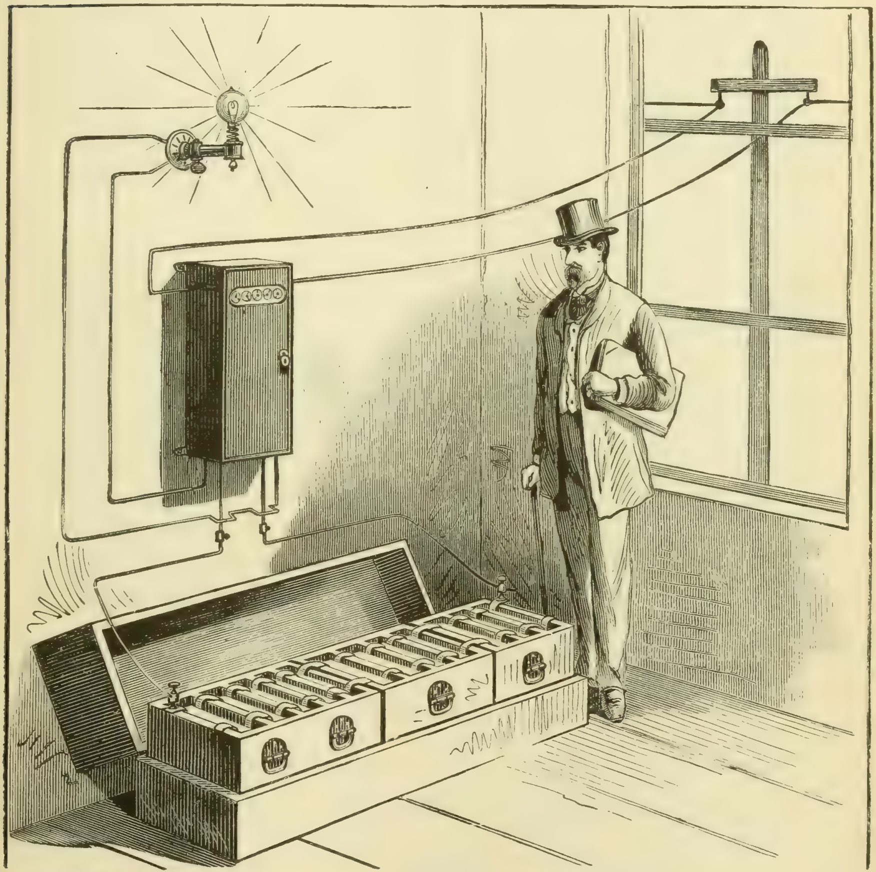

Fig. 147.

and second to utilize the arc light plant at times when it would otherwise be idle, thus virtually diminishing the interest on the investment.

It is claimed that the employment of storage batteries not only produces a perfectly steady light, but the uniformity of the current insures great durability in the carbon filament of the lamp.

The storage battery used on the evening referred to was charged by the current from a No. 8 Brush dynamo at the Elizabeth Street station, which at the same time furnished thirty-four arc lamps on a circuit a little over ten miles in length, the conductor being a No. 6 copper wire. The battery consisted of twenty-four elements, and furnished a current to twenty-seven sixteen-candle power Swan lamps. The carbon filament was maintained in a high state of incandescence, emitting a very steady white light.

The general appearance of the storage battery is shown in figure 147. It consists of lead plates arranged by pairs in cells and connected in series. Each battery of twenty-four cells is connected with the current manipulator fixed to the wall, and the charging current entering the manipulator is switched from one battery to another automatically by the manipulator, and when all of the batteries are fully charged they are cut out of the dynamo circuit by the same means. When either of the batteries is partially exhausted, it is switched into the charging circuit by the manipulator, and even while receiving its charge the battery may be supplying its current to the lamps, the needs of the battery being provided for by the manipulator, which also records the amount of current used.

The sizes and capacity of the cells are given below.

Size of cells.	Capacity in Swan lamps.	Size of plates in inches.	Number of cells required for Swan lamps.
No. 1	5 to 8	8 x 8	20
" 2	10 " 15	8 x 16	20
" 3	20 " 30	8 x 16	20
" 4	40 " 60	16 x 16	20

These batteries, we are assured, will furnish 9 to 10 lights of the size or power of an ordinary 5 feet gas burner (usually 16-candle power), for each horse power absorbed by the dynamo electric machine used in charging them. This is said to be partly due to the greater efficiency of the battery, and partly to the use of a distributing and charging current of comparatively high electro motive force. It is claimed that this kind of electric current permits the use of small conductors and long circuits in charging the secondary batteries, while the batteries yield a current of low potential adapted to incandescent lighting.

All danger from short circuiting the lamp or wires is avoided by means of an exceedingly simple and inexpensive device, consisting of a strip of tinfoil secured to the face of a piece of vulcanized fibre, the tinfoil forming a part of the circuit. When the lamp is short circuited, the tinfoil melts and is thrown off from the strip of fibre, thus interrupting the circuit. The vulcanized fibre with its attached tinfoil is readily replaced.

The Brush Electric Company assert that this system of lighting is now entirely beyond the experimental stage, and that it is commercially practicable and ready for the public.

In addition to the extensive works already in operation in Cleveland, the Brush Electric Company is erecting a large building to be supplied with steam power to the extent of 1,000 horse power, for the purpose of manufacturing the new storage battery.

THE BERNSTEIN INCANDESCENT LAMP.

It is a somewhat singular coincidence that in another work we have described two systems of simultaneous transmission of electric signals in the same direction upon one wire, one of which was invented by A. Bernstein and the other by T. A. Edison, and that in this work the same names appear as inventors of two systems of incandescent electric lighting ; the coincidence, however, does not extend to the persons : for, while it is the same Edison in both cases, it is not the same Bernstein, the inventor of the system of incandescent lighting being the son of the inventor of the system of simultaneous transmission

The Bernstein Electric Light System consists of a dynamo machine or generator of the electric current; incandescent lamps which are connected by wires with the generator, and are provided with holders, switches and cut-outs; and meters for measuring the amount of current passing through the wires.

The generator, which is shown in Fig. 148, is based on the principle of the Paccinotti machine. It is constructed in such a way, that currents of either high or low electro motive force can be generated at the same speed by connecting the armature coils in different ways, thus allowing the use of the same machine for different purposes. The division of the armature into several parts allows change of polarity in the armature cores with little heating, and the large surface of wire exposed to the air helps to keep the machine cool.

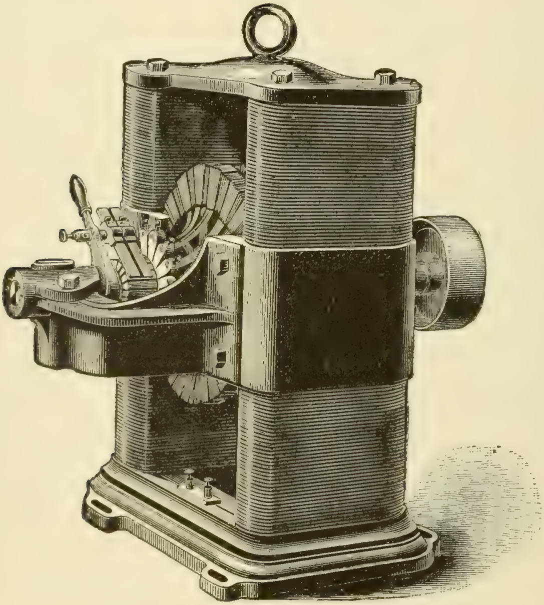

Fig. 148.

The magnets are comparatively large and the magnetic field very intense. Arrangements are made to increase or decrease the magnetic force according to the requirements of the outside circuit. There is no wear and tear on these machines except at the two bearings and on the commutator brushes, which are mounted on a movable shaft and allow of easy adjustments. The machine is so simple, that it can be easily handled by any engineer without previous knowledge of electrical matters.

Besides being adapted for the purposes of electric lighting the machine can be used for the transmission of power by means of electricity and for electric railways.

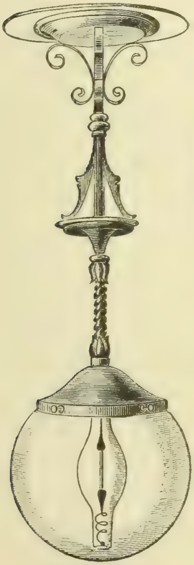

Fig. 149.

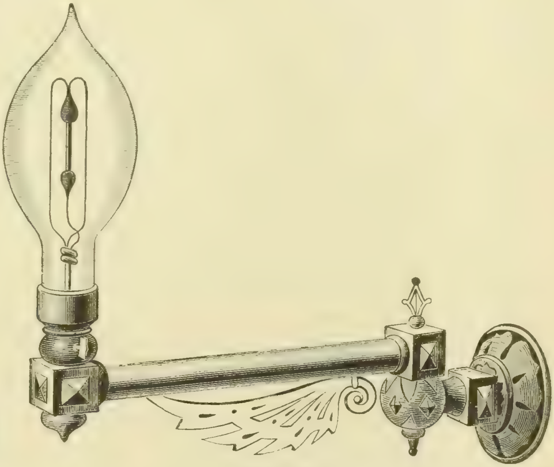

Fig. 150.

The lamp is shown in two different forms in Figs. 149 and 150. The lamp in Fig. 149 consists of a cylinder of glass with a bulb blown in the centre. Into the bulb the carbon is introduced, and the connection established by means of fine platinum wires sealed into the ends of the lamps after the manner of the Geissler tube. The difficulty of making suitable carbons of this kind, and of attaching them to the conducting wires in a practicable manner has been overcome in an exceedingly satisfactory manner, viz.: the connections between the carbon and conducting wires being made in such a manner as to relieve the carbon of all strain by expansion and contraction when in use. The form shown in Fig. 150 is the one more commonly used.

The lamp is fastened into a socket, which can readily be attached to any ordinary gas chandelier or bracket. By means of a switch connected with the socket the light can be let on or off at pleasure. In case a lamp should break by accident, a new one can instantly be put into the place of the broken one.

In the Bernstein lamp the light-giving carbon is not heated in a vacuum, but the lamp is filled with a vapor, which has a preserving action on the carbon. Another point which distinguishes this lamp from other electric lamps, in use at the present time, is the large light-giving surface and consequent large volume of light obtained—the light-giving surface being eight times as large as in the ordinary filament lamp.

In judging of the amount of light produced by an electric lamp, one is often misled by the brilliancy of the light. This brilliancy merely results from the fact, that an intense light is radiated from a small light-giving surface; if the same amount of light could be obtained from a larger light-giving surface, the lamp would not appear as brilliant, but would be more pleasant to the eye, and the light would be of a more diffusive character.

The Bernstein lamp is made in fifty, twenty-five and twelve candle power, and for purposes where stronger lights are desirable, lamps up to 500-candle power can be furnished.

Automatic cut-outs are made both for lamps arranged in multiple arc and in series.

In the first case the cut-out prevents undue heating of the wires if they are accidentally or purposely brought in contact with each other. If the lamps are placed in series, an automatic cut-out is used, which closes the circuit around the lamp, in case it should be broken or give out for any other reason.

The meter, invented by Mr. Bernstein, registers automatically the amount of electric energy consumed in every house, and in such a way as to allow the producer and consumer to read the amount at any time from dial plates. It consists of a fulcrumed scale-beam, which carries at one end a traversing and counterbalanced registering device and at the other end a coil into which is placed a soft iron core connected by a rod to the register. Below the arm carrying the registering device is suspended a coil, which is surrounded by a second coil of larger diameter, the latter being constantly traversed by the main or branch current, while the smaller coil and the coil on the beam are traversed by a branch from the main current through a shunt of very high resistance. The registering device and scale-beam are retained in a position of rest—to wit, a horizontal position—by means of a spring-catch and fixed rack-bar, which latter is arranged above the registering device. The strength of the current in the inner coil depends on the difference of potential between the two points of the shunt, connected respectively with the two branch conductors, and, therefore, indicates volts. The time is practically measured by the number of indications made, so that the total indication depends on these three elements, viz.: volts, ampères and time.

In order to indicate by mechanical means the distance through which the register moves, the arm of the scale-beam which carries the register is made in the shape of a rack, and the registering device provided with a small pinion, which gears with the rack and transmits its motion by a train of gear-wheels to index-hands moving over dial-plates in the usual manner. The hands of the dial can only be moved when the registering device moves in one direction, they not being moved when the registering device moves in the opposite direction, so that the return motion of the register has no effect upon the hands. In this way the strength of the main current is indicated by means of the shunted current, and thereby the amount of current passing over the main line or in any branch to which the meter is applied accurately determined.

In connection with the registering device of the current-meter, and above the same, is arranged a fixed horizontal rack-bar, which is engaged by means of a spring-catch, applied to the register. As soon as the shunted current is made to pass through the inside coils the beam is deflected at the left end, and the iron core will be drawn inside of the coil at the right end. As the register is drawn toward the right by the action of the coil on the iron core until equilibrium is again established, the beam assumes again a horizontal position, and no further motion of the register can take place, as the spring-catch engages the fixed rack-bar. The distance which the sliding register is compelled to move in order to establish equilibrium of the beam corresponds directly to the strength of the main current to be measured. Unlike other electric meters, which only give the amount of current passed, this meter measures the total amount of electric work done, viz.: volt x ampère x time.

The advantages claimed for the Bernstein are the following:

That it is the cheapest artificial light yet produced, whether compared with gas or with other systems of electric lighting. That as compared with other incandescent systems, more available candle power is produced for each horse power used in the motor; 150 to 500 candles being obtained per horse power, according to the current and style of lamp used. That the lamp is more durable, and the light steadier; and that the light produced being large in volume and very diffusive, fills the space well and is agreeable to the eye.

THE LANE-FOX INCANDESCENT LAMP.

The form of the Lane-Fox lamp (figure 151) is very similar to the Edison; both make a single loop of the carbon, which is bent into a horse-shoe form. The filament of the Lane-Fox lamp is made from grass fibres of the kind known as French whisk or bass broom, used in making carpet brushes. The fibres are boiled in a strong solution of potash or soda, and the skin scraped off and then the soda or potash is boiled out of them, and they are stretched around a mould of plumbago, and baked at a white heat. The fibres are then further carbonized by depositing carbon upon them from a rich hydrocarbon gas. This is done by suspending them in large globes filled with bengole, and then heated to incandescence by an electric current. The gas is decomposed by the white hot filament, and carbon is deposited on its surface, by which means the fibre is covered with a hard carbon skin, which produces the requisite resistance and renders the filament more uniform, thus insuring greater durability. The carbons are of various thickness, some being used in lamps of 10 and 20 and others of 30 and 60 candle power.

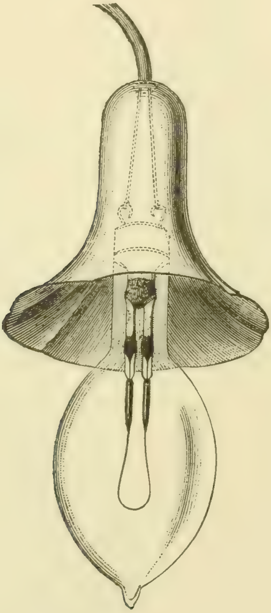

Fig. 151.

Mr. Lane-Fox's method of distributing the current is similar to Edison's, except that he uses the earth instead of a return wire. The lamps are placed in multiple arc and a constant electro-motive force of about 100 volts is maintained in the circuit. An automatic regulator is employed to insure this result, which is placed in the circuit between the main conductor and the earth. The regulator (figure 152) consists of an electro-magnet, E″, through which a shunted portion of the current passes, and attracts the armature of lever L, pivoted at H. This lever plays between the two adjustable contact pins I and v, resting midway when the current is of the proper intensity, but striking the upper pin I, if the current becomes too strong, and the lower pin v, if it becomes too weak. By this means a local circuit is closed, and more or less resistance is inserted in the circuit of the field-magnets of the generator, so as to bring the lighting current to its normal value, and the lever of the regulator to its mid position. This resistance is inserted automatically. E is a vibrating electro-magnet, analogous in its action to the buzzer of an electric bell, which is caused by the local current to rotate a vertical axis N, carrying at its upper end a small toothed pinion, which can gear with either of the two like wheels R and R′, enclosing it between their toothed edges. If it gear with the wheel R, the horizontal spindle D, carrying these two wheels, will be rotated in one direction, and if it gear with R′ the same spindle will be rotated in the other direction, and as the spindle D carries at its lower end a vertical shaft connected with the sliding contact arm F, F, which moves over the contact pieces c, c, of a series of resistances contained in the box, it throws in or takes out resistance from the field magnet. The direction in which the horizontal spindle shall turn is determined by the two electro-magnets E and E′. According as the lever L touches I or v, one or other of these electro-magnets E or E′ attracts the armature A, placed between their opposed poles, which moves the spindle D longitudinally, and brings the pinion-headed axis into gearing with one or other of the two wheels R and R′ on the horizontal spindle.

Secondary batteries are used to store any surplus current and return it to the circuits when there is any falling off in those below the normal current. They are so arranged that the battery in discharging will automatically adapt the potential of its discharge to the needs of the mains as determined by the regulator.

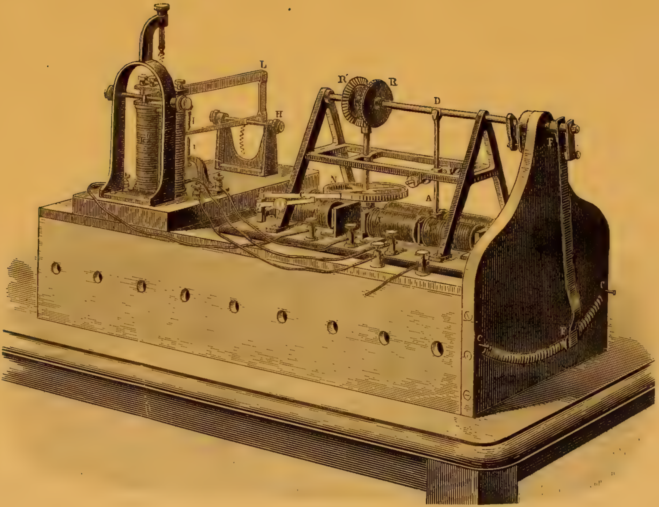

Fig. 152.

Mr. Lane-Fox has invented three kinds of meters for measuring the current used in his lamps. The Lane-Fox system is now worked by the Anglo-American Brush Electric Light Corporation, and was exhibited with fine effect at the Crystal Palace Exhibition, where the Alhambra Courts were lighted by Lane-Fox lamps fed from a Sellon-Volckmar secondary battery charged by a Brush machine, and the light was conveniently graduated by switching on a greater or less number of cells of the battery.

CHAPTER V.

REPORT ON THE INCANDESCENT LAMPS EXHIBITED AT THE INTERNATIONAL EXPOSITION OF ELECTRICITY, PARIS, 1881.

I.—DESCRIPTION OF THE LAMPS.

The only lamps in the Exhibition which were purely incandescent in character were those of Edison and Maxim, in the United States section, and those of Swan and Lane-Fox, in that of Great Britain. The idea represented in these lamps is essentially the same in all of them, the differences being, for the most part, details of construction. They all consist of a glass envelope, more or less spherical in form, in which is inclosed a carbon loop, made of carbonized organic material, and supported upon

Fig. 153.

wires of platinum sealed into the glass. The space in the interior of the lamp is very perfectly exhausted.

A. THE EDISON LAMP.—The Edison lamp (figure 153) is pear-shaped in form. The carbon filament is long and fine, and is bent into the shape of a U. It is made from Japanese bamboo, cut to the requisite size in a gauge. In section it is nearly square, being about 0.3 millimètre on a side, the ends being left considerably wider. The fibre is carbonized in moulds of nickel, and is attached to the conducting wires by copper, electrolytically deposited upon them.

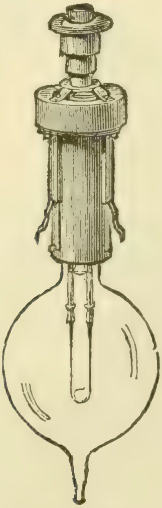

Fig. 154.

B. THE SWAN LAMP.—The Swan lamp (figure 154) is globular in form, the neck being quite long. The carbon filament is made from cotton thread, parchmentized before carbonization by treatment with strong sulphuric acid. The ends of this filament are very much thickened, and the loop has a double turn at the top. Its ends are clamped in a pair of metal holders, supported laterally by a stem of glass which rises through the neck to the base of the globe. Below, these holders are fastened to wires of platinum which pass through the glass.

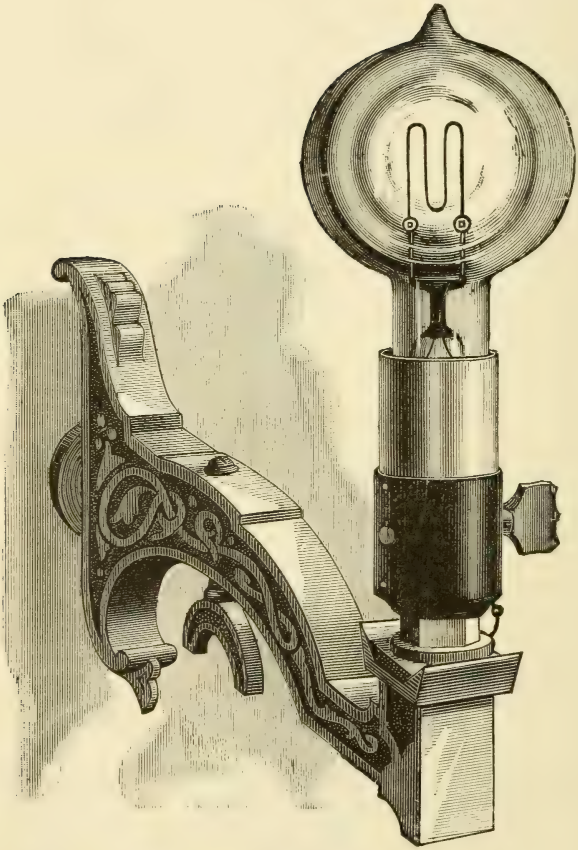

Fig. 155.

C. The Maxim Lamp.—The Maxim lamp (figure 155) is also globular in form, but it has a short neck. Within the neck rises a hollow cylinder of glass, supporting upon its summit a column of blue enamel, through which pass the conducting wires of platinum which carry the carbon. The filament is made from cardboard cut by a punch into the form of an M. In section, therefore, it is rectangular, and several times as broad as it is thick. It is carbonized in a mould through which a current of coal gas is passed. After carbonization, the filament is placed in an attenuated atmosphere of hydrocarbon vapor, and heated by the current. The vapor is decomposed, and its carbon is precipitated upon the filament. In this way not only are inequalities obliterated, but the resistance of the filaments may be equalized, and brought to any standard required.

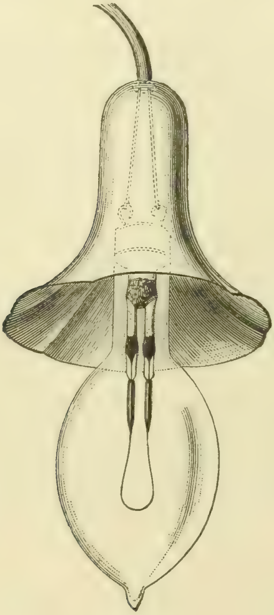

Fig 156.

D. The Lane-Fox Lamp.—The Lane-Fox lamp (figure 156) is ovoid in shape, the neck being in length intermediate between the two lamps last described. The carbon is in the form of a horse shoe, and is circular in cross-section. It is made from the root of an Italian grass, largely used in France for making brooms. After carbonization, the filaments are classified according to their resistances. They are then heated in an atmosphere of coal gas in which carbon is deposited upon them, as in the filaments of the lamps last described. The filament in the lamp is supported by platinum wires, to which it is attached by sleeves of carbon encircling both. These wires pass through tubes in the top of the hollow glass stem. Just below the extremities of these tubes are two small bulbs containing mercury, forming the contact between the platinum wire sealed into the glass above and the conductor which enters from below. These conductors are held in place by plaster, which fills the base of the lamp.

II.—METHODS OF MEASUREMENT.

The question to be determined was simply the efficiency of these lamps. The efficiency of a lamp is the ratio of energy produced to energy consumed—that is, the quantity of light given by the lamp for each horse-power of current which it consumes. The data required to calculate this efficiency may be obtained when the electro-motive force of the current, the resistance of the lamp when giving its light, and its illuminating power, have been determined.

1. *Electro-motive Force.*—The electro-motive force, or fall of potential through the lamp, was measured by Law's method. A suitable condenser was charged by being put in communication with a standard Daniell cell, and then discharged through a high resistance galvanometer, the deflection of the needle being noted. This condenser was then connected to the two wires of the lamp, and again discharged through the galvanometer, the deflection being made the same as before by means of a variable shunt connected with the galvanometer. Since with a given condenser the charges it receives are proportional to the potentials of the

charging currents, and since the discharge deflections of a galvanometer represent the quantity of these charges, it follows that the electro-motive forces are proportional to these discharge deflections. If, however, as in the present case, the discharge deflections are made equal by means of shunts, then the electromotive forces are proportional to the multiplying power of the shunts.

2. *Resistance*—The resistance of the lamp, when giving its light, was obtained by making the lamp one side of a Wheatstone's bridge through which the main current was flowing. The second and fourth sides were formed of fixed resistances of known value, and the third side of an adjustable resistance. When the bridge is balanced, the product of the two fixed resistances, divided by the adjusted resistance, gives the resistance of the lamp at the given candle-power.

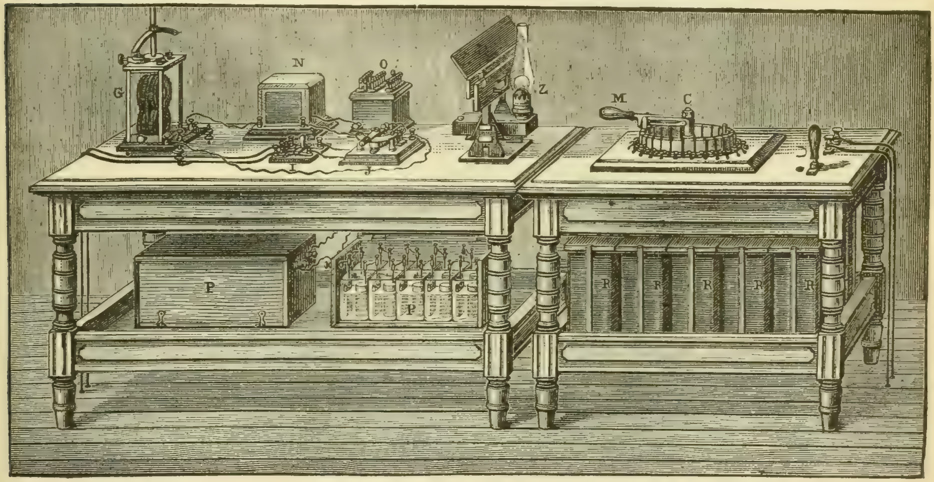

Fig. 157.

3. *Illuminating Power.*—The illuminating power of the lamp was measured on a Bunsen photometer. At one end of the bar was the lamp itself; at the other end two standard candles, placed nearly in line. The plane of the carbon filament was

placed at 45° to the length of the bar, and each lamp was measured at 16 and 32 candles.

III.—APPARATUS EMPLOYED.

1. *Condenser.*—The condenser (N, fig. 157) used in these measurements, had a capacity of one microfarad, divided into sections of 0·4, 0·3, 0·2, and 0·1. The dielectric was paraffined mica, and the brass work was supported on ebonite pillars. Made by Latimer Clark, Muirhead & Co., London, and exhibited in their section at the Exhibition.

2. *Galvanometer.*—The galvanometer (G, fig. 157) was a Thomson double-coil astatic instrument, enclosed in a square case with glass sides. Measured resistance, 6,550 ohms. Used with lamp stand and scale in the ordinary way. Made by Elliott Brothers, London.

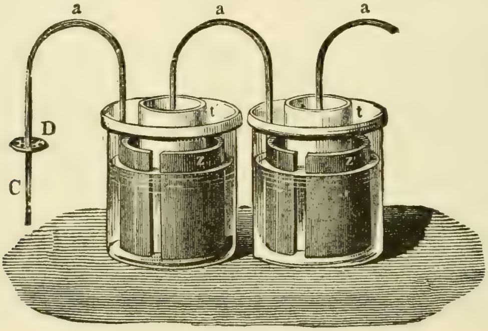

Fig. 158.

3. *Standard Cell.*—An ordinary Daniell cell (fig. 158), the copper plate being immersed in a saturated solution of pure copper sulphate, contained in the porous cell, and the zinc plate amalgamated, in a saturated solution of pure zinc sulphate, in the outer jar; one of a battery of ten cells forming a part of the Edison exhibit.

4. *Resistance Coils.*—(*a.*) A set of standard coils, measuring from 1 ohm to 5,000 ohms. All other resistances employed were

standardized by these. Made by L. Clark, Muirhead & Co., and a part of their exhibit. (*b*.) A set of coils used in the Wheatstone's bridge. Compared carefully with set (*a*). These coils formed a part of the exhibit of Edison.

5. *Wheatstone's Bridge* (fig. 159).—Four conducting wires of large size arranged on the table in the form of a rhomb. A test galvanometer was inserted between the obtuse angles of the rhomb, and a pair of shunt wires from the main conductors were attached at the acute angles. The first side of the rhomb contained the lamp to be measured, standing in its place on the photometer. The second side contained a fixed resistance of 5 ohms. The third side contained a variable resistance (Resistance *b*); and the fourth side a fixed resistance of 950 ohms. This bridge formed a part of the Edison exhibit.

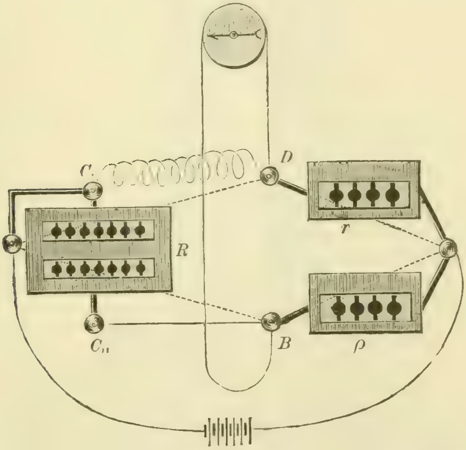

Fig. 159.

6. *Photometer.*—The photometer employed was of the Bunsen form, having a double bar, 80 inches long, graduated in inches and in candles. The disk was of paraffined paper, with a plain spot in the centre. The disc box was movable on rollers, and contained inclined mirrors to facilitate the adjustment. The candles used were of spermaceti, made by Sugg of London, to

burn 120 grains (7.776 grammes) per hour. The entire apparatus was surrounded with heavy black cloth. Also a part of the Edison exhibit

7. *Dynamo-electric Machine.*—An Edison sixty-light machine (fig. 160) was used to furnish the current required. In this machine the field magnets, which are very long and heavy, stand vertically. The field is maintained by a shunt current, regulated by an adjustable resistance in its circuit. The bobbin is wound on a cylinder like that of Siemens, from which it differs, however, in its details. Its resistance was only 0·03 ohm, and the current delivered, at a speed of 900 revolutions, had an electro-motive force of 110 volts. A part of the Edison exhibits.

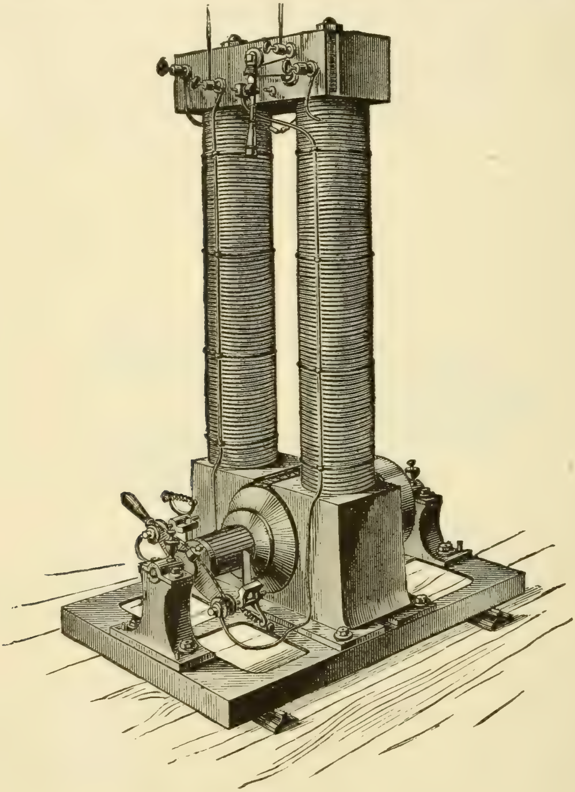

Fig. 160.

IV.—RESISTANCE OF LAMPS COLD.

The resistance of the lamps cold was measured on a Wheatstone's bridge of the ordinary form and in the usual way. The Edison lamps were taken at random from the stock on hand. The Swan lamps were furnished by Mr. Edmunds, the Lane-Fox lamps by Mr. Stewart, and the Maxim lamps by Mr. Lockwood. Twenty-four of each were taken (except the Lane-Fox, of which only fifteen were furnished), and ten selected from these for the tests. The measurements of the Edison and Swan lamps were made by Mr. E. G. Acheson; those of the Lane-Fox and Maxim lamps by Mr. H. Crookes. The following are the results obtained:

Number.	Edison.	Swan.	Lane-Fox.	Maxim.
1	237	74	53	73
2	233	50	56	84
3	268	54	56	76
4	260	73	56	74
5	251	55	54	74
6	228	72	50	71
7	227	39	53	68
8	249	67	52	63
9	219	55	57	65
10	237	52	63	73
Mean...	241	59	55	72

V.—MEASUREMENT OF EFFICIENCY.

1. *Experimental Results.*

A. THE EDISON LAMP.—In this measurement the entire condenser was employed. When charged with the standard cell and discharged through the galvanometer without shunt, a deflection of 310 scale divisions was obtained, as a mean of ten closely accordant experiments. The photometer readings were made by

Mr. Crookes, the bridge readings by Major R. Y. Armstrong, and the galvanometer readings by Prof. G. F. Barker.

(*a.*) AT 16 CANDLES.

Number of Lamp.	Photometer Reading.	Bridge Reading.	Galvanometer Reading.
1	16—14.75	35—34.5	75
2	16—15	35.0	74
3	16	30.5	74
4	16	32.3	73
5	16—17	33.4	73
6	16—17.5	36.0	73
7	16—15	36.6	78
8	16	34.5	75
9	16—19	37.5	74
10	16	37.7	74

(*b.*) AT 32 CANDLES.

Number.	Photometer.	Bridge.	Galvanometer.
1	32	37.2	66
2	32	37.2	65
3	32	37.3	66
4	32	34.3	64
5	32	35.2	67
6	32	37.9	69
7	32	38.5	69
8	32	36.3	69
9	32	38.9	69
10	32	38.8	69

B. THE SWAN LAMP.—The entire condenser was used in these measurements also, the deflection being 310 divisions. The photometer was read by Mr. H. Crookes, the bridge by Mr. Crookes, and the galvanometer by Professor Barker.

(*a*.) AT 16 CANDLES.

Number.	Photometer.	Bridge.	Galvanometer.
1	16	119.5	136
2	16	161.7	145
3	16	148.8	137
4	16	113.5	122
5	16	145.9	134
6	16	122.1	138
7	16	229.0	179
8	16	135.1	145
9	16	159.5	146
10	16	171.0	145

(*b*.) AT 32 CANDLES.

Number.	Photometer.	Bridge.	Galvanometer.
1	32	123.5	121
2	32	167.2	122
3	32	155.2	121
4	32	116.0	116
5	32	154.7	115
6	32	129.7	120
7	32	237.0	146
8	32	137.5	128
9	32	163.0	127
10	32	175.2	120

C. THE LANE-FOX LAMP.—The entire condenser was employed, and the deflection was the same, 310 divisions. Mr. H. Crookes read the photometer, Mr. Crookes the bridge, and Professor Barker the galvanometer.

(*a.*) AT 16 CANDLES.

Number.	Photometer.	Bridge.	Galvanometer.
1	16	172.0	150
2	16	168.7	145
3	16	177.6	161
4	16	171.7	157
5	16	171.0	156
6	16	189.5	156
7	16	179.0	156
8	16	181.1	164
9	16	161.7	146
10	16	164.7	148

(*b.*) AT 32 CANDLES.

Number.	Photometer.	Bridge.	Galvanometer.
1	32	178.7	135
2	32	175.5	129
3	32	181.2	149
4	32	175.2	148
5	32	175.7	143
6	32	192.3	143
7	32	186.2	146
8	32	184.5	146
9	32	167.3	133
10	32	172.0	129

D. THE MAXIM LAMP.—The entire condenser was used, as in the previous cases. But the deflection obtained was 315 divisions, owing probably to the higher temperature of the room. Photometer read by Mr. H. Crookes, bridge by Mr. Crookes, galvanometer by Professor G. F. Barker.

(*a*.) AT 16 CANDLES.

Number.	Photometer.	Bridge.	Galvanometer.
1	16	111.8	115
2	16	111.3	119
3	16	106.2	111
4	16	124.7	120
5	16	111.9	122
6	16	138.5	121
7	16	122.0	122
8	16	115.6	118
9	16	120.6	123
10	16	103.0	111

(*b*.) AT 32 CANDLES.

Number.	Photometer.	Bridge.	Galvanometer.
1	32	114.6	102
2	32	114.8	106
3	32	109.7	100
4	32	128.6	112
5	32	114.5	112
6	32	140.8	113
7	32	126.9	110
8	32	120.4	105
9	32	126.5	110
10	32	109.7	101

E. THE CANDLE RECORD.

1. EDISON LAMP.

Candle Power.	Loss in Grms.	Time in Mins.	Loss per Min.
16	18.13	73	0.2483
32	21.22	84	0.2526

2. SWAN LAMP.

16 and 32	34.15	126	0.2695

3. LANE-FOX LAMP.

16 and 32	40.70	153.75	0.2647

4. MAXIM LAMP.

16 and 32	26.90	104	0.2586

2. *Methods of Calculation.*

1. *Illuminating Power.*—The standard candle should burn 7.776 grammes of spermaceti per hour, or 0.1296 gramme per minute. The two candles used should burn 0.2592 gramme per minute. The corrected candle power of the lamp, therefore, is obtained by the proportion: As 0.2592 is to the amount actually burned per minute, so is the observed candle-power to the corrected candle-power.

2. *Resistance* (*hot*).—From the theory of the Wheatstone's bridge, the resistance of either side is equal to the product of the adjacent sides divided by the opposite side. In the bridge used for the measurement, the resistance in the two adjacent sides were 950 and 5 ohms. Hence by dividing their product, 4,750, by the reading of the variable resistance observed, the resistance of the lamp hot is obtained.

3. *Electro-motive Force.*—In Law's method the electro-motive forces are proportional to the multiplying power of the shunts employed. Since with the Daniell cell no shunt was used, the multiplying power of the shunt used with the lamp-current represented directly the electro-motive force through the lamp, in terms of the standard cell. The multiplying

power of a shunt is the sum of the galvanometer resistance, and the shunt resistance divided by the shunt resistance. In this case the resistance of the galvanometer was 6,550 ohms. Hence if S represent the resistance of the shunt, obtained by experiment, $\frac{6{,}550+S}{S}$ will represent the electro-motive force. Since the electro-motive force of a Daniell cell is not 1 volt, as here assumed, but 1.079 volts, strict accuracy would require the figures given to be increased in that ratio. Moreover, the small error arising from the inductive action of the needle on the galvanometer-coils has been regarded as unimportant.

4. *Current.*—By the law of Ohm the current strength is the quotient of electro-motive force by resistance. Dividing the electro-motive force in volts by the resistance in ohms, the current-strength is obtained in ampères.

5. *Electrical Energy.*—The work done by a current is proportional to the product of the square of the current-strength into the resistance of the circuit. Or, since the electro-motive force is equal to the product of the current-strength by the resistance, the energy is represented by the product of the electro-motive force in volts by the current-strength in ampères. This gives the energy in volt-ampères.

6. *Mechanical Energy.*—Since an absolute unit of work is done per second by an absolute unit of electro-motive force in a circuit of one absolute unit of resistance, 1 volt-ampère represents 10^7 absolute units of mechanical work per second, or 0·10192 kilogram-metre. By multiplying the volt-ampères by 0·10192, the product is the mechanical work done in the lamp in kilogram-metres.

7. *Lamps per Horse Power of Current.*—One horse power is 75 kilogram-metres per second. By dividing 75, therefore, by the number of kilogram-metres of work done in the lamp per second, the quotient is the number of such lamps maintained by a horse power of current.

8. *Candles per Horse Power of Current.*—The number of candle lights per horse power of current is obtained, of course,

by multiplying the number of lamps per horse power of current by the corrected candle power of each.

9. *Normal Lamps per Horse Power of Current.*—Conversely, by dividing the number of candles per horse power of current by the normal value of the lamp in standard candles (in the present case 16 or 32), the number of normal lamps per horse power of current is obtained.

3. *Calculated Results.*

A. THE EDISON LAMP.

(*a.*) AT 16 CANDLES.

No.	Candles (corrected.)	Ohms.	Volts.	Ampères.	Volt-Ampères.	Kilogram-mètres.	Lamps per Horse Power.	Candles per Horse Power.
1	14.73	136.7	88.33	0.646	57.08	5.819	12.88	189.8
2	14.85	135.7	89.51	0 660	59.05	6.020	12.46	185.0
3	15.33	155.7	89.51	0.575	51.46	5.246	14.29	219.1
4	15.33	147.3	90.73	0.616	55.88	5.697	13.16	201.8
5	15.81	142.2	90.73	0.638	57.88	5.901	12.71	200.8
6	16.04	132.0	90.73	0.687	62.36	6.357	11.80	189.3
7	14.85	129 8	84.97	0.655	55.63	5.671	13.22	205.0
8	15.33	137.7	83.33	0.641	56.67	5.777	12.98	199.0
9	16.76	126.6	89.51	0.707	63.29	6.453	11.62	194.9
10	15.33	126.0	89.51	0.710	63.45	6.469	11.60	177.7

A. THE EDISON LAMP.

(*b.*) AT 32 CANDLES.

No.	Candles (corrected.)	Ohms.	Volts.	Ampères.	Volt-Ampères.	Kilogram-mètres.	Lamps per Horse Power.	Candles per Horse Power.
1	31.11	127.7	100.20	0.785	78.70	8.023	9.35	291.0
2	31.11	127.7	101.80	0.797	81.11	8.269	9.07	282.2
3	31.11	147.5	100.20	0.679	68.12	6.945	10.80	333.7
4	31.11	138.5	103.30	0.746	77.12	7.862	9.54	296.8
5	31.11	134.9	98.76	0.732	72.28	7.369	10.18	316.6
6	31.11	125.3	95.93	0.765	73.42	7.486	10.02	311.7
7	31.11	123.4	95.93	0.778	74.59	7.604	9.86	306.9
8	31.11	130.8	95.93	0.733	70.32	7.169	10.46	325.4
9	31.11	122.1	95.93	0.786	75.36	7.683	9.76	303.7
10	31.11	122.4	95.93	0.784	75.17	7.633	9.79	304.5

B. THE SWAN LAMP.

(*a.*) AT 16 CANDLES.

No.	Candles (corrected.)	Ohms.	Volts.	Ampères.	Volt-Ampère	Kilogram-mètres.	Lamps per Horse Power.	Candles per Horse Power.
1	16.61	39.75	49.16	1.237	60 80	6.199	12.10	200.9
2	16.61	29.38	46.17	1.536	72.57	7.399	10 14	168.3
3	16 61	31.92	48.81	1.529	74.63	7.609	9.86	163.7
4	16.61	41.85	54 69	1.307	71.47	7.286	10.29	170.9
5	16.61	32.56	49.88	1.532	76.42	7.791	9.63	159.8
6	16.61	38.90	48.47	1.246	60.38	6.155	12.18	202.3
7	16.61	20.74	37.59	1.812	68.13	6.946	10.80	179.3
8	16.61	35.16	46.17	1.313	60.64	6.182	12.13	201.5
9	16.61	29.78	45.86	1.540	70.62	7.201	10.41	173.0
10	16.61	27.78	46.17	1.662	76.75	8.824	9.59	159.5

B. THE SWAN LAMP.

(*b.*) AT 32 CANDLES.

No.	Candles (corrected.)	Ohms.	Volts.	Ampères.	Volt-Ampères.	Kilogram-mètres.	Lamps per Horse Power.	Candles per Horse Power.
1	33.21	39.36	55.13	1.401	77.23	7.87	9.526	316.4
2	33.21	28.41	54.69	1.925	105.30	10.73	6.988	232.1
3	33.21	30.61	55.13	1.801	99.31	10.12	7.407	246.0
4	33.21	40.95	57.47	1.403	80.64	8.22	9.122	302.9
5	33.21	30.71	57.96	1.888	109.40	11.15	6.725	223.3
6	33.21	36.62	55.58	1.514	84.36	8.60	8.720	289.6
7	33.21	20.09	45.86	2.288	104.90	10.70	7.010	232.5
8	33.21	34.54	52.17	1.510	78.79	8.03	9.337	310.1
9	33.21	29.14	52.57	1.804	94.85	9.67	7.756	257.6
10	33.21	27.11	55.58	2.050	114.00	11.62	6.456	214.4

C. THE LANE-FOX LAMP.

(*a*.) AT 16 CANDLES.

No.	Candles (corrected)	Ohms.	Volts.	Ampères.	Volt-Ampères.	Kilogram-mètres.	Lamps per Horse Power.	Candles per Horse Power.
1	16.36	27.62	44.65	1.617	72.25	7.365	10.18	166.6
2	16.36	28.16	46.17	1.640	75.72	7.719	9.72	158.9
3	16.36	26.75	41.68	1.559	64.96	6.623	11.33	185.2
4	16.36	27.66	42.72	1.544	65.97	6.726	11.15	182.4
5	16.36	27.78	42.99	1.548	66.52	6.782	11.06	180.9
6	16.36	25.07	42.99	1.715	73.72	7.516	9.98	163.2
7	16.36	26.54	42.99	1.620	69.64	7.100	10.56	172.8
8	16.36	26.23	40.94	1.561	63.90	6.515	11.51	188.3
9	16 36	29.37	45.86	1.561	71.60	7.300	10.27	168.1
10	16.36	28.85	45.26	1.569	71.02	7.240	10.36	169.4

C. THE LANE-FOX LAMP.

(*b*.) AT 32 CANDLES.

No.	Candles (corrected.)	Ohms.	Volts.	Ampères.	Volt-Ampères.	Kilogram-metres.	Lamps per Horse Power.	Candles per Horse Power.
1	32.71	26.58	49.52	1.863	92.25	9.405	7.98	260.9
2	32.71	27.07	51.78	1.913	99.04	10.100	7.43	243.0
3	32.71	26.09	44.96	1.723	77.47	7.898	9.50	310.7
4	32.71	27.11	45.26	1.669	75.56	7.702	9.74	318.6
5	32.71	27.04	46.80	1.731	81.03	8.261	9.08	297.1
6	32.71	24.70	46.80	1.895	88.69	9.042	8.30	271.4
7	32.71	25.51	49.16	1.927	94.74	9.659	7.77	254.0
8	32.71	25.75	45.86	1.781	81.70	8.330	9.00	294.6
9	32.71	28.39	50.25	1.770	88.93	9.066	8.27	270.7
10	32.71	27.62	51.78	1.875	97.07	9.896	7.58	247.9

D. THE MAXIM LAMP.

(*a.*) AT 16 CANDLES.

No.	Candles (corrected).	Ohms.	Volts.	Ampères.	Volt-Ampères.	Kilogram-metres.	Lamps per Horse Power.	Candles per Horse Power.
1	15.96	42.49	57.96	1.364	79.06	8.060	9.305	148.5
2	15.96	42.68	56.04	1.313	73.59	7.503	9.996	159.6
3	15.96	44.73	60.01	1.342	80.51	8.208	9.137	145.9
4	15.96	38.09	55.58	1.459	81.11	8.269	9.070	144.8
5	15.96	42.45	54.69	1.288	70.46	7.183	10.440	166.7
6	15.96	35.10	55.13	1.571	86.61	8.830	8.494	135.6
7	15.96	38.94	54.69	1.405	78.62	7.832	9.577	152.9
8	15.96	41.09	56.51	1.375	77.71	7.923	9.466	151.1
9	15.96	39.39	54.25	1.377	74.73	7.619	9.844	157.2
10	15.96	46.12	60.01	1.301	78.09	7.961	9.421	150.4

D. THE MAXIM LAMP.

(*b.*) AT 32 CANDLES.

No.	Candles.	Ohms.	Volts.	Ampères.	Volt-Ampères.	Kilogram-metres.	Lamps per Horse Power.	Candles per Horse Power.
1	31.93	41.45	65.22	1.573	105.00	10.710	7.006	223.7
2	31.93	41.34	62.79	1.519	95.38	9.724	7.713	246.3
3	31.93	43.30	66.50	1.536	102.10	10.410	7.203	230.0
4	31.93	36.94	59.48	1.610	95.79	9.766	7.680	245.2
5	31.93	41.49	59.48	1.434	85.29	8.695	8.625	275.4
6	31.93	33.74	58.96	1.743	103.00	10.510	7.138	227.9
7	31.93	37.43	60.54	1.617	97.93	9.984	7.512	239.8
8	31.93	39.45	63.38	1.607	101.80	10.380	7.225	230.7
9	31.93	37.55	60.54	1.612	97.62	9.954	7.536	240.6
10	31.93	43.30	65.85	1.521	100.20	10.210	7.346	234.5

4. *Summary of Results.*

(*a.*) AT 16 CANDLES.

	Edison.	Swan.	Lane-Fox.	Maxim.
Candles	15.38	16.61	16.36	15.96
Ohms	137.4	32.78	27.40	41.119
Volts	89.11	47.30	43.63	56.49
Ampères	0.641	1.471	1.593	1.38
Volt-Ampères	57.98	69.24	69.53	78.05
Kilogram-metres	5.911	7.059	7.089	7.93
Lamps, per horse power	12.73	10.71	10.61	9.48
Candles, per horse power	196.4	177.92	173.58	151.270
Lamps of 16 candles per horse power.	12.28	11.12	10.85	9.45

(*b.*) AT 32 CANDLES.

	Edison.	Swan.	Lane-Fox.	Maxim.
Candles	31.11	33.21	32.71	31.93
Ohms	130.03	31.75	26.59	39.60
Volts	98.39	54.21	48.22	62.27
Ampères	0.7585	1.758	1.815	1.578
Volt-Ampères	74.62	94.88	87.65	98.41
Kilogram-metres	7.604	9.67	8.936	10.03
Lamps, per horse power	9.88	7.90	8.47	7.50
Candles, per horse power	307.25	262.49	276.89	239.41
Lamps of 32 candles per horse power.	9.60	8.20	8.65	7.48

VI.—CONCLUSIONS.

The following conclusions seem to be sustained by the results which have now been given :—

First.—The maximum efficiency of incandescent lamps in the present state of the subject, and within the experimental limits of this investigation, cannot be assumed to exceed 300 candle-lights per horse power of current.

Second.—The economy of all lamps of this kind is greater at high than at low incandescence.

Third.—The economy of light-production is greater in high resistance lamps than in those of low resistance, thus agreeing with the economy of distribution.

Fourth.—The relative efficiency of the four lamps examined, expressed in Carcel burners of 7.4 spermaceti candles each, produced by one horse power of current, is as follows:—(A.) At 16 candles: Edison, 26.5; Swan, 24; Lane-Fox, 23.5; and Maxim, 20.4. (B.) At 32 candles: Edison, 41.5; Lane-Fox, 37.4; Swan, 35.5; and Maxim, 32.4. To double the light given by these lamps the current energy was increased, for the Maxim and Lane-Fox lamps, 26 per cent.; for the Edison lamp, 28 per cent.; and for the Swan lamp, 37 per cent.

CHAPTER VI.

ARC AND INCANDESCENT LIGHT LAMPS, CANDLES AND REGULATORS.

THE WERDERMANN ELECTRIC LAMP.

The Werdermann electric lamp partakes of the nature both of an incandescent and of a voltaic arc lamp, and constitutes an intermediate system which ought to fulfil certain special conditions. The invention consists in keeping a small vertical pencil of carbon in contact with a large horizontal disk of the same material above it.

Referring to No. 1 of Figure 162, which shows the ordinary arrangement of carbons in an electric lamp, it is well shown that when the passage of the current is such that the top carbon is a positive pole, the end of this carbon becomes cup-shaped, while the end of the other carbon becomes pointed by the action of the current. By increasing the lower carbon considerably in sectional area, Mr. Werdermann found that, with the same amount of current passing, it was necessary in order to maintain the continuity of the arc, to place the two carbons closer together; he also noticed (as a curious fact) that a little cylindrical pimple of carbon was formed in the middle of the lower carbon electrode, as shown by the figure, also the end of the upper carbon tended to spread out. On still further increasing the size of the lower electrode, it was found necessary to bring the two carbons still closer together, in order to maintain the continuity of the arc; the little cylindrical pimple then became much smaller in size, and the end of the upper carbon spread out still more. If, now, the lower carbon was still further enlarged, so that it had a sectional area sixty-four times as large as that of the upper carbon, it was found that the continuity of the circuit could only be maintained by keeping the two carbons in actual contact, and further, it was observed, that the end of the upper carbon, which had previously tended to spread out, now took a pointed form. When actual contact took place the little pimple of carbon disappeared, and a brilliant light was given out by the incandescent point.

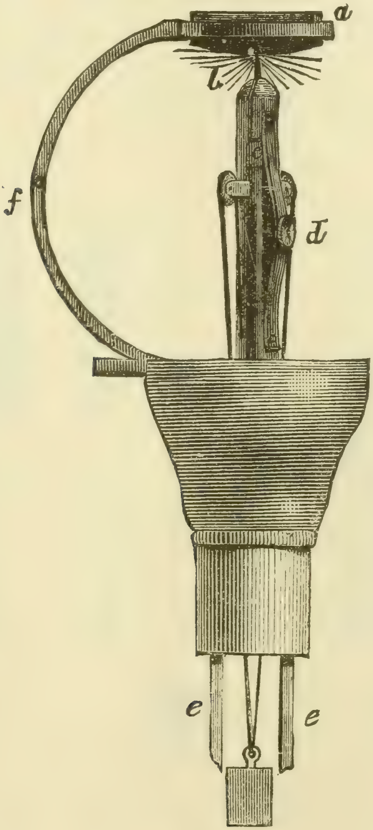

Fig. 161.

Nos. 5, 6, and 7 of Fig. 162 show what occurred when the larger carbon formed the positive pole. Under these conditions the end of the small electrode became heated to a red heat only, while a small portion only of the large electrode became heated to a white heat by the passage of the current; this was also the case when the upper electrode was increased in size, and the two carbons had to be approached closer together in order to maintain the arc. When, however, the upper carbon was increased to such a size that continuity could only be maintained by actual contact, then a curious change took place; the upper carbon no longer glowed, but the point of the smaller carbon, previously only red hot, now became white-hot, and assumed the conditions shown by No. 4. The light given out when the larger carbon formed the positive pole was found to be not quite so great as when it formed the negative pole. The heat being almost entirely confined to the smaller carbon, the larger one was not consumed to any appreciable extent.

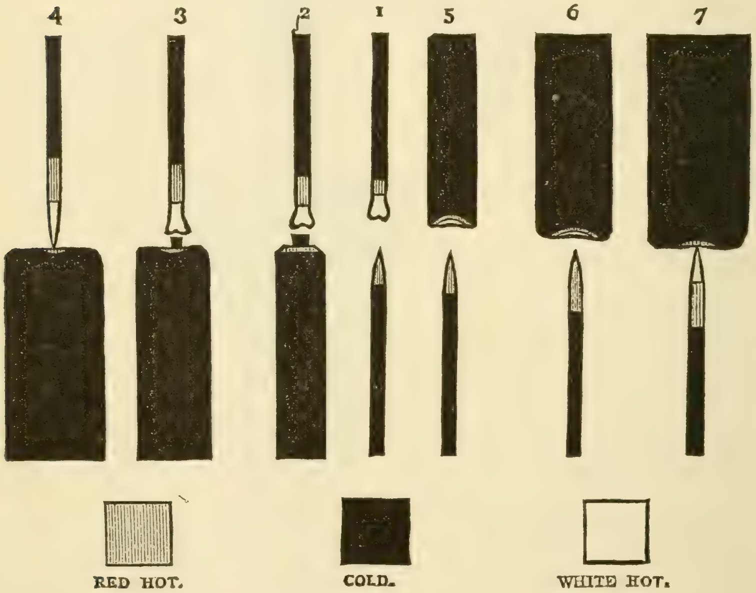

Fig. 162.

During the whole time that the smaller carbon burns, it retains its pointed form, and a small electric arc is plainly visible round the points of contact of the two carbons. The greater part of the light given out is produced by this small arc.

In accordance with the foregoing results, Mr. Werdermann constructs his lamps in the following manner:

He places the negative electrode uppermost, giving it the form of a solid disk of carbon, about two inches in diameter and one inch thick. This is encircled by a band of copper ribbon and prolonged to a terminal to which one of the machine wires is attached. The lower or positive carbon, which is a thin round pencil, one tenth of an inch in diameter, is placed vertically beneath the negative electrode, in a tube up which it slides. This tube has a prolongation of thick copper divided in two parts, and, pressing against the pencil and forming contact with it, this forms the other terminal of the lamp.

The lower carbon is kept in contact with the upper one by chains attached to its lower extremity, coming up over pulleys and down again to a counterbalance weight, which always keeps the point of the pencil in gentle contact with the disk as the former gradually burns away.

By referring to the sketch, Fig. 161, the general idea of the lamp will be seen at a glance. *a* is the negative carbon, *b* is the pencil sliding in the tube, *c*, and gripped at the top of the tube, by the split contact piece, the pressure of which is regulated by the spring, *d*. The conductors, *e*, form part of the lamp post having terminals at the bottom, and one is connected to the tube, the other, by means of the semicircular piece of metal, *f*, to the upper carbon; *f* is hinged for the purpose of moving away the negative disk when a globe is to be put on the lamp.

The tube is shown in perspective for the sake of greater clearness.

Figure 163 shows the connections of ten lamps supplied from a Gramme machine.

The thick wires + and — are the cables connecting the lamps with the Gramme machine, the first lamp on the positive being the last on the negative. The spirals, *a*, are equal resistances placed in the circuit of each lamp for the purpose of rendering any variation in the contact or pressure of the two carbons less appreciable to the passage of the branch currents.

The resistance of the large lamp is rather less than that of the small ones. In the 10 small lamps the carbon pencils burn away at the rate of about 2 inches per hour.

The average resistance of each small lamp, including the extra resistance, *a*, is 0.392 ohm; 5 lights parallel is .076 ohm; 10 lights, parallel, as exhibited, is 0.037 ohm.

The large lamps, having pencils of 4½ mm. diameter, burn from 2½ to 3 inches per hour.

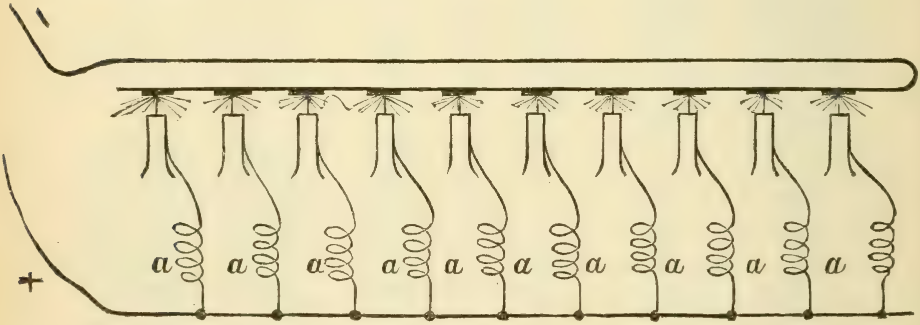

Fig. 163.

The carbons are manufactured in Paris in lengths of about one yard, and at a cost of about 20 cents per yard, which length would keep up a light for 12 hours.

The negative disks are of ordinary battery carbon, and the weight required to keep carbons in contact is about 1½ lbs.

The length of carbon protruding from the tube and made incandescent, is ¾ of an inch, but this length can be varied at pleasure. However many lights may be put in circuit the extinction of one or more will not affect the rest, a switch arrangement attached to each lamp effecting all that is required for the regulation of the current.

Then again, by this system, all the lamps are lighted simultaneously, and can all be as readily extinguished, and again relighted.

Two tall lamps for outdoor lighting, connected in parallel circuit, give a light estimated at 360 candles each.

The lamps have no globes, and the lights are wonderfully clear, of a pure color, and perfectly free from the blue or purple rays so often seen in the electric arc, and are remarkable for steadiness of burning, there being an entire absence of any jumping or flickering.

The ten small lamps were estimated to give about 40 candles each; each one burned with the same brilliancy and steadiness.

In regard to the strength of this light, one object of the inventor is to moderate the intensity, so as to avoid having any of the illuminating power reduced by covering the lamps with opal or ground glass globes, as in other systems. The two large lamps did not dazzle the eyes, there being no change of color and no jumping, so it is, therefore, the intention of Mr. Werdermann to use ordinary glass globes, so that scarcely any loss of light will be incurred.

To some questions put to him by a gas engineer, Mr. Werdermann aptly compared the quantity of current with the quantity of a gas holder, and the electro-motive force of the current to the pressure of gas. For instance, if a gas holder held sufficient gas, and had enough pressure to supply 100 burners, it would be necessary to increase the quantity and pressure of the gas to equally light 200 jets. It is the same with the electric light. If with one machine of given quantity and electro-motive force, 100 lights can be produced, then if 200 lights are required, we must have a machine with a greater quantity of current (corresponding to the capacity of the gas holder), and with greater electro-motive force to carry the lights further away (answering to the pressure of gas).

The Werdermann electric lamp has recently been brought out in a new form at Paris by its inventor, and one which is a great improvement on the original model. In the new form (Figure 164), the inventor has endeavored to regulate the pressure of the lateral contact on the carbon rod according to the pressure that the latter exerts on the upper disk. To this end the upper carbon disk is placed on a beam, the equilibrium of which is regulated by a screw weight. This beam carries a small arm placed in the interior of the globe, and which exerts on the movable lateral contact of the carbon a pressure which is so much the greater in proportion as that of the vertical carbon increases. This pressure retards the upward movement of the carbon rod. We have here, then, a sort of brake, the equilibrium of which depends on the way in which the regulation

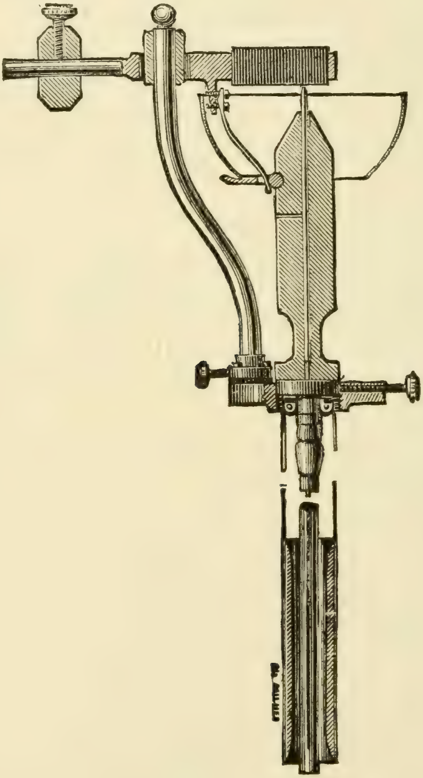

Fig. 164.

has been effected beforehand by means of the counterpoise. In measure as the carbon wastes away, the lateral contact loosens a little, and allows the carbon rod to move upward. In this arrangement, which permits of very light contacts between the rod and the disk, there is never any breaking of the point, but there is a regular wear, and consequently a great steadiness of the light.

As several lamps are mounted in tension in the same circuit, if one of them should be extinguished, it is necessary that it should be at once thrown out of the circuit to prevent the extinguishment of the rest. This result is obtained by the same lever which serves to press on the lateral contact. When the rod is no longer resting against the disk, the latter descends, and the lever strikes against a metallic catch, which establishes a direct communication, and throws the lamp out of the circuit. At a recent experiment at the Paris Opera House, twelve of these lamps, slightly modified for the occasion, were grouped on four

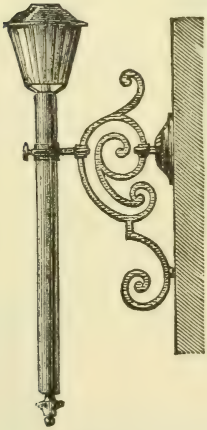

Fig. 165.

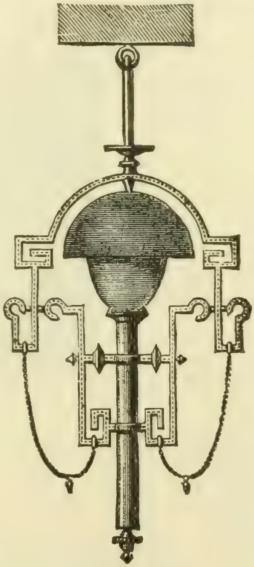

Fig. 166.

lusters, and were supplied by two Gramme machines, each having in its circuit six lamps mounted in tension. In the absence of photometric measurements, it is at present impossible to give an opinion as to the economic value of the lamp under consideration, and unfortunately the want of just such data is too frequent at a time when with every invention is connected the question of dollars and cents. Mr. Werdermann proposes to apply his apparatus to domestic lighting. Figure 165 represents a wall lamp, and Figure 166 a hanging lamp, which show how the apparatus may be constructed for decorative purposes, although these particular forms leave much to be desired from an artistic point of view.

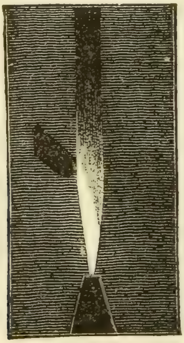

Fig. 167.

THE REYNIER ELECTRIC LAMP.

The Reynier lamp may be considered an intermediate system between the voltaic arc and the incandescent light in a vacuum. The light furnished by this lamp is white, and more powerful than the incandescent. Some improvements have lately been effected in this lamp, which was patented in 1878. Figures 167 and 168 will illustrate the principle and form of the original lamp, which may be briefly described as follows: If a small carbon pencil is pressed laterally, by an elastic contact, and pushed forward, following its axis on a fixed contact, and is traversed between these two contacts by a powerful current, it will become incandescent in that part, and will burn and grow thinner towards the end. The objections to these lamps are: the contacts make too much shadow, derive a certain degree of heat by conductibility, and the action of the lateral contact is very delicate.

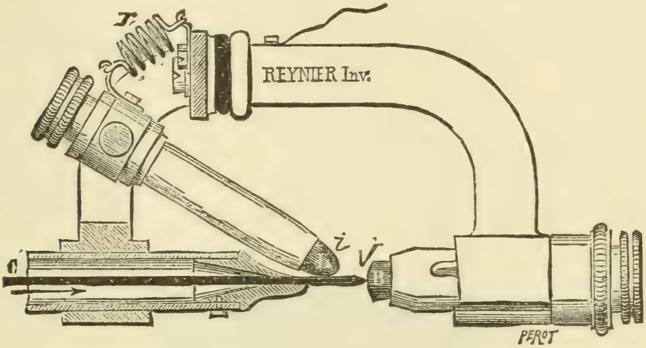

Fig. 168.

The elevation of the temperature, at the point arising from the imperfect contact, Mr. Reynier believes he can make use of in an

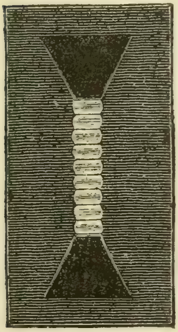

Fig. 169.

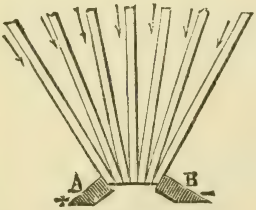

Fig. 170.

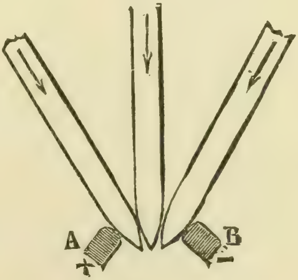

Fig. 171.

incandescent lamp in vacuum, by making a graphite conductor in several parallel horizontal parts, or slices (figure 169) and tightening them to a moderate degree between two contacts. In making his lamp, however, he met with some practical difficulties, and then he formed the idea of having the imperfect contacts superposed in an incandescent lamp, in free air, and having the carbon pencils automatically renewed, according as they wore out.

For this purpose he uses several carbon rods, arranged in fan form (figure 170) at their base, between two fixed contacts, which bring on the current n carbons, furnish $n+1$ contacts, the carbons following one another, and lying like the voussoirs of an arch.

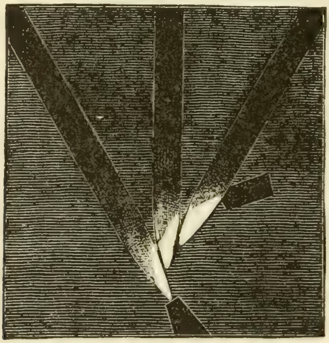

Fig. 172.

The arrangement indicated in figure 170 is only realizable with very thin carbons in the transverse direction; carbons of round or square section take a wolf's tooth form (figure 171) which is unfavorable to the luminous effect of the apparatus, for the points relatively cold which stand out from the dissected conductor are the seat of a very important superfluous emission of heat.

This difficulty has been met by using a sectioned conductor in broken line (figure 172). The current traverses each rod obliquely, and leaves no points outside of the circuit. This arrangement requires a lamp of triangular form, flat, and much too wide in the upper part (figure 173); but with very flat carbons, the system will be simplified.

M. Reynier has made a simpler model for ordinary round carbons, in which he utilizes both the thinned carbon (figure 174), and the principle of imperfect contacts, while he places only two carbons in the apparatus. Two pencils, thinned down at one end, are placed in the same plane, and almost parallel;

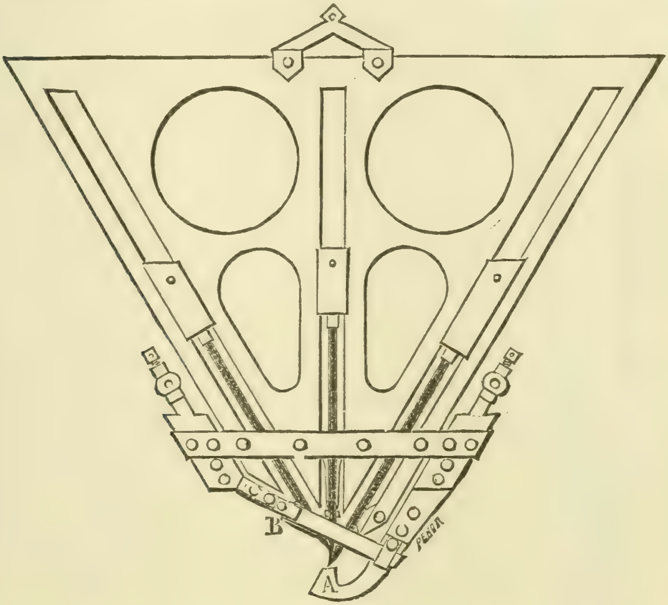

Fig. 173.

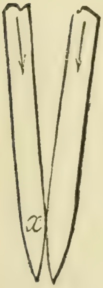

Fig. 174.

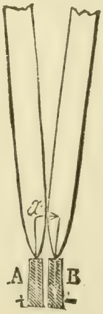

Fig. 175.

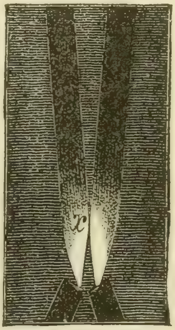

Fig. 176.

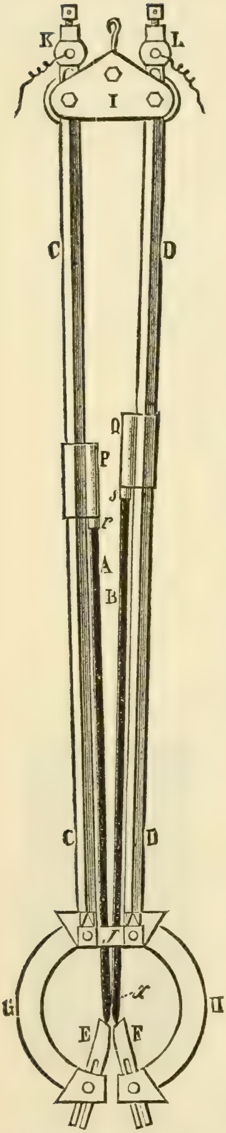

Fig. 177.

the points are facing each other and the pencils are brought together to touch at one point. The points being free, they can rest upon two contacts, A and B (figure 175), and thus obtain an incandescent system in which the electric current traverses successively, in the opposite direction, the two pointed ends passing from one to the other by their lateral mutual contact.

To maintain the parts in this condition, notwithstanding the combustion of the points, it is necessary to continuously impel the carbons in a longitudinal direction, and to give to the supporting contacts a suitable obliquity (figure 176); the rods ought also to be guided in their common plane. Under these conditions, the pointed form is maintained; the carbons continue to impinge upon their respective contacts, and to touch each other at a certain distance above the points. Figure 177 represents one practical form given to the apparatus. The carbons, A and B, are respectively impelled by weights, P and Q, sliding upon two metallic guides, C and D. The oblique contacts, E, F, are two sheets of copper, fixed upon bronze arcs, G, H. Two pairs of insulated clamps, I and J, connect the two halves of the lamp; the first pair is of wood, the second is of slate, and forms a slot, which guides the two carbons in their common plane.

The weights, P and Q, are insulated from the carbons which they impel, by ivory caps, *r* and *s*.

The electric current, entering by the terminal K, follows the brass guide, C, the bend, G, the contact, E, goes up the pointed extremity of the carbon, A, passes over the contact, x, descends by the carbon end, B, and follows the contact, F, the bend, A, and the guide, D, to the terminal, L.

The two extreme contacts make little shadow; the middle contact causes on loss of heat or light, and usefully increases the total resistance of the lamp.

This combination of the two incandescent points, close together, and the three neighboring contacts, produces a concentration of heat that favors the luminous power. The light has great fixity, comparable to that of the vacuum incandescent lamp, and is whiter; analogous to that of the arc, while it is free from its troublesome variations of color and constancy.

The lamp is worked with pretty intense currents—30 to 40 ampères—but requires only a small electro-motive power—8 to 10 volts. A small number of accumulators, or large surface piles, will, therefore, be sufficient to supply such a lamp. More extended experiments will enable us to form a more decided opinion as to the merits of the system, which, it is claimed, will be superior to the weaker arc lights.

SOLIGNAC'S NEW ELECTRIC LAMP.

When it becomes a question of practical lighting, it is very certain that the best electric lamp will be the one that is most simple and requires the fewest mechanical parts. It is to such simplicity that is due all the success of the Jablochkoff candle and the Reynier-Werdermann lamp. Yet, in the former of these lamps, it is to be regretted that the somewhat great and variable resistance opposed to the current in its passage through two carbons that keep diminishing in length, in measure as they burn, proves a cause of loss of light and of variation in it. And it is also to be regretted that the duration of combustion of the carbons is not longer; and, finally, it is allowable to believe that the power employed in volatilizing the insulator placed between the carbons is prejudicial to the economical use of this system.

In order to obviate this latter inconvenience, an endeavor has been made in the Wilde candle to do away with the insulator, but the results obtained have scarcely been encouraging. An endeavor has also been made to render the duration of the carbons greater by employing quite long ones, and causing these to move forward successively through the intermedium of a species of rollers, or of counterpoises, as in the lamps of Mersanne and Werdermann; but then the system becomes more complicated. Finally, in order to keep the resistance of the carbons at a minimum and constant, their contact with the rheophores of the circuit has been established at a short distance from the arc, and this is one of the principal advantages possessed by the Reynier-Werdermann system. At one time it was thought that the problem might be simply solved by arranging in front of each other two carbons actuated by a spiral spring, as in car lamps, and kept at a proper distance apart for forming the electric arc by two funnel-shaped pieces of calcined magnesia, into which they entered like a wedge in measure as their conical point wore away through combustion. This was the system of Mr. De Baillehache, and the trials that were made therewith were very satisfactory. But, unfortunately, the magnesia was not able to resist very long the temperature to which it was submitted. The problem found a better solution in the sun lamp, but has been solved in another manner, and just as simply, by Mr. Solignac, and the results obtained by him have been very satisfactory as regarded from the standpoint of steadiness of the luminous point.

In this system, a general view of which is given in Fig. 178, and the details in Figs. 179 and 180, the carbons, F F, which are horizontal and about 18 inches in length, are thrust toward each other by two barrels, K, K, which wind up two chains, E, E, passing around the pulleys, D, D, fitted to the extremities of the carbons. These latter are provided beneath with small glass rods, G, G, whose extremities toward the arc abut at a short distance from the latter against a nickel stop, L (Fig. 180), which supports them, moreover, at M, by means of a tappet, whose position is regulated by a screw. The current is transmitted to the carbons by two friction rollers, I I, which serve at the same time as a guide for them, and which give the electric flux a passage of only one third of an inch over the front of the carbon to form the arc. Finally, the whole is held by a support, A, and two pieces, C B, C B, which at the same time lead the current to the friction rollers through projections, J. The two systems are made to approach or recede from each other, in order to form the arc, by means of a regulating screw, H.

At present, the lighting of these lamps is effected by means of this screw, H, but Mr. Solignac is now constructing a model in which the lighting will be performed automatically by means of a solenoid that will react upon a carbon lighter, as in several already well known systems.

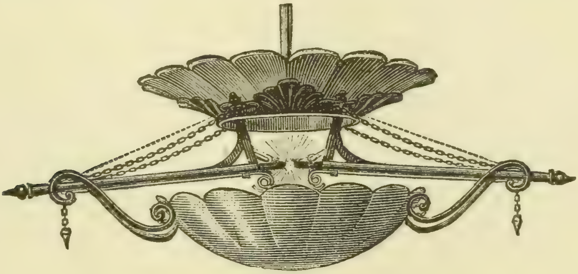

Fig. 178.

It will be seen that the carbons are arrested in their movement toward each other only by the glass rods, G, abutting against L; but, as the stops, L, are not far from the arc, and as the heat to which they are exposed is so much the greater in proportion as the incandescent part of the carbons is nearer them, it results that for a certain elongation of the arc the temperature becomes sufficient to soften the glass of the rods, G, G, so that they bend as shown at O (Fig. 180), and allow the carbons to move onward until the heat has sufficiently diminished to prevent any further softening of the glass. In measure as the wearing away progresses, the preceding effects are reproduced; and, as these are produced in an imperceptible and continuous manner, no jumping nor inconstancy in the light of the arc is perceived. Under such conditions, then, the regulation of the arc is effected under the very influence of the effect produced; and not under that of an action of a different nature (electro-magnetism), as happens in other regulators. It is certain that this idea is new and original, and the results have been very satisfactory. There is but one regulation to perform, and that at the beginning, but this once done the apparatus operates with certainty, and for a long time. With a Meritens machine of the first model it has been found possible to light five lamps of this kind placed in the same circuit.

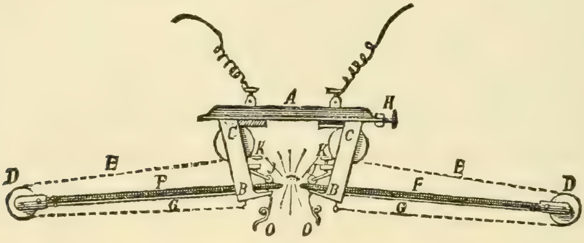

Fig. 179.

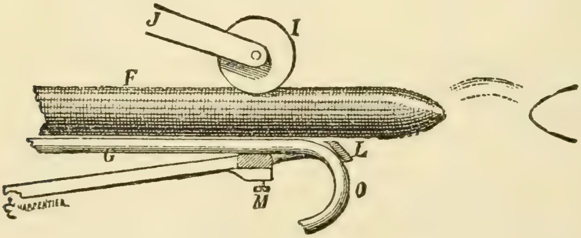

Fig. 180.

According to the inventor, this lamp will give a light of 100 carcels with one horse power, and with three horse power six lamps may be lighted.

The cost of the glass rods is one cent per foot. They can, then, be considered only as an insignificant expense in the cost of the carbons. We consequently believe that it will be possible to employ this system advantageously in practice.

THE MONDOS ELECTRIC LAMP.

Since the month of May, 1882, the concerts at the Champs Elysées in Paris have been lighted by sixteen voltaic arc lamps on a new and very simple system, which gives excellent results in the installation under consideration. The sixteen lamps are on the divisible system, and their regulation is based upon the principle of derivation. They are supplied by a Siemens alternating current machine and arranged in four circuits, on each of which are mounted four lamps in series. Figures 181 and 182 will enable the reader to readily understand the system, which is as simple as it is ingenious, and which has been arranged by Mr. Mondos so as to obtain a continuous and independent regulation of each lamp.

In this system the lower carbon is stationary, the luminous point descending in measure as the carbons wear away through combustion. The upper carbon descends imperceptibly by its own weight, so as to keep the arc at its normal length.

The mechanism that controls the motions of the upper rod that supports the carbon holder consists of two bobbins of fine wire, E (Fig. 182), mounted on a derived circuit on the terminals of the lamp; of a lever, L, articulated at O, and supporting a tube, TT′, and the whole movable part balanced by a counterpoise, P. This lever, P, carries two soft iron cores, F, which enter the bobbins, E, and become magnetized under the influence of the current that passes through them. The upper part of the tube, T, carries a square upon which is articulated at O′ a second lever, L′, balanced by a second counterpoise, P′, and carrying a flat armature, *p*, opposite the cores, F, that are fixed to the first horizontal lever, L. The carbon holder rod, CC′, slides freely in tube, TT′, and is wedged therein by a small piece, *a m l* fixed to the lever, L′. For this reason the tube, TT′, is provided with a notch opposite the piece *a m l*, and the two arms, *a* and *m*, of the latter are shaped like a V, as may be seen in part in the plan in Fig. 182. It is now easy to understand how the system operates; when the current is not traversing the circuit, the carbons are separated; but, at the moment the circuit is closed for lighting a series of lamps, it traverses the electro-magnet, which then becomes very powerful, and draws

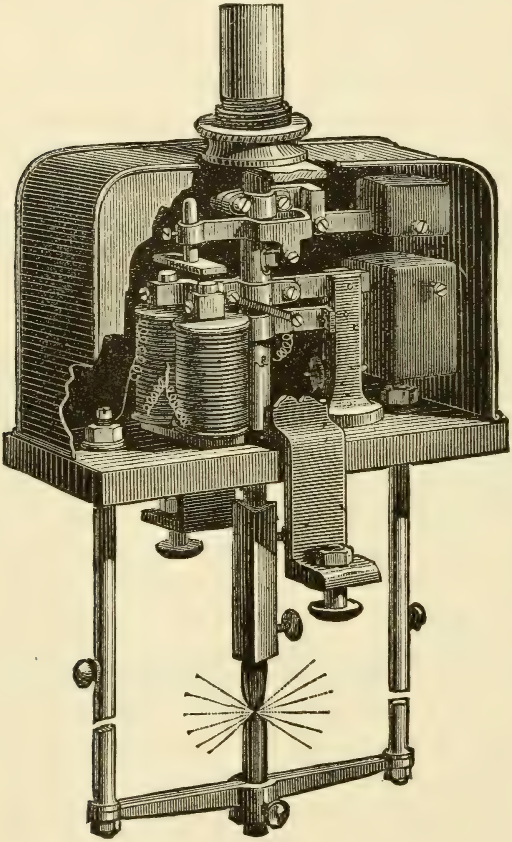

Fig. 181.

down the cores, F, along with the lever, L, the tube, TT′, and the carbon holder, CC′, and brings the carbons in contact. The arc then forms, and the current divides between the arc and the bobbins, E. Its action upon the cores, F, becomes weak, and it can no longer balance the counterpoise, P, which falls back, and raises the system again. The arc thus becomes primed. The cores, F, however, preserve a certain amount of magnetization; the armature, *p*, is attracted, and the lever, L′, assumes a position of equilibrium such that the piece, *a m l*, wedges the rod, CC′, in the tube, TT′, and holds it suspended. When, through wear of the carbons, the arc elongates, a greater portion of the current passes into the bobbins, E, the armature, *p*, is attracted with more force, and the lever, L′, swings around the point, O′. The rotation of L′ separates the piece, *a m l*, from the rod, CC′, which, being thus set free, slides by its own weight and shortens the arc. The current then becomes weak in E, the armature, *p*, is not so strongly attracted, the lever, L′, pivots slightly around O′ under the action of the weight, P′, and the brake or wedge enters the notch anew, and stops the descent of the carbon. In practice, the motions that we have just described are exceedingly

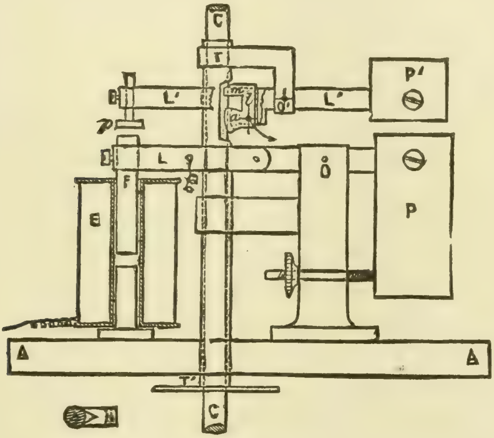

Fig. 182.

slight; the carbon moves imperceptibly, and the length of the arc remains invariable.

It will be seen, then, that the lever, L, and the tube, TT′, serve exclusively for lighting, and the lever, L′, exclusively for regulating the distance of the carbons.

This lamp exhibits great elasticity, and can operate, without a change of any part of its mechanism, with currents of very different intensities. It suffices for obtaining a proper working of the apparatus in each case, to regulate the distance from the weight, P′, to the point of suspension, O′, and the distance from the armature, *p*, to the cores, F. At the Champs Elysées concerts the lamps are operating with alternating currents; but they are capable of operating with continuous ones also, although the slight tremor of the electro-magnetic system, due to the use of alternating currents, and, as a consequence of rapid changes of magnetization, seems in principle very favorable to systems in which the descent of the carbon is based upon friction instead of a clutch. At the Champs Elysées concerts the lamps burn carbons of 4 to 5 inches, with a current of 9 to 10 ampères, and an effective electro-motive power of 60 volts per lamp. The light is very steady, and the effect produced is most satisfactory. The dispensing with all clock work movement and regulating springs makes this electric lamp of Mr. Mondos a simple and plain apparatus, capable of numerous applications in the industries, in wide, open spaces, in all cases where foci of medium intensity have to be employed, and where it is desired to arrange several lamps in the same circuit.

THE PILSEN ELECTRIC LIGHT ARC LAMP.

The Pilsen Electric Light Arc Lamp is the invention of two Austrian engineers, Messrs. Ludwig Piette and Franz Krizik, and is so called owing to the difficulty of correctly pronouncing the names of the inventors, Pilsen being the name of the town where the lamp was invented.

The special and novel feature of this lamp is the use and action of a biconical or spindle-shaped iron core when suspended between, and partly through, the interiors of two magnetic solenoids, placed one above the other, through which an electrical current is passing. When so used, such a core has no positive or balanced position, and can be moved, and will remain in any new position.

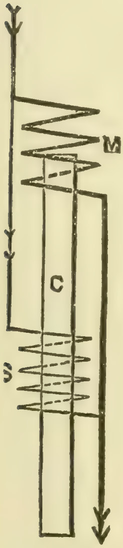

Fig. 183.

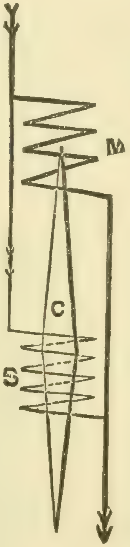

Fig. 184.

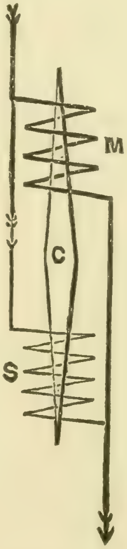

Fig. 185.

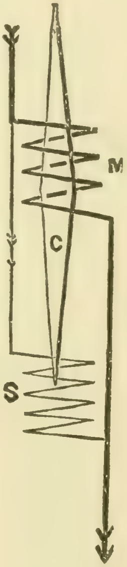

Fig. 186.

When a cylindrical iron core of the ordinary form is placed inside a solenoid coil, and an electrical current is sent through that coil, the iron core takes up a positive and balanced position in the coil, and, as is well known, when moved out of that position, always tries to regain it. With two coils, M and S, placed one above the other (Fig. 183), the cylindrical core, C, will take up a position between the two, exactly in proportion to the magnetic power of each; any alteration of the current passing through either coil will disturb the balance, and cause the iron core to move up or down, and upon the balance being restored the core will return to its former position. The limit of such movement, however, is, in practice, soon reached; whilst the use of a cylindrical core necessitates clockwork gearing and releasing apparatus of a complicated nature, as instanced in the application of that system in Messrs. Siemens' differential electric light lamp, and others of that type.

In the Pilsen Lamp, on the other hand, the double-coned iron core, within the limit of half its length, is not so affected by moving, and has no such balanced position; and thus it has a very long extent of movement, which is utilized directly to feed the carbons in an electric light lamp, and so avoids the use of complicated mechanism.

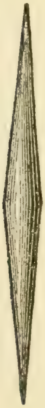

Fig. 187.

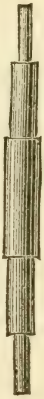

Fig. 188.

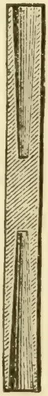

Fig. 189.

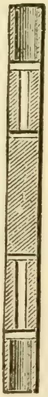

Fig. 190.

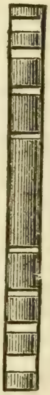

Fig. 191.

Fig. 184 shows the double-coned iron core, C, in a similar position, between the two coils, M and S, to that of the cylindrical core in Fig. 183. Fig. 185 shows the core half way between the two coils. Fig. 186 shows the core in the reverse position to Fig. 184. In each and all of these positions, and in any intermediate position, the action upon the coned iron core is the same, and it has no tendency to move up or down.

Figs. 187, 188, 189, 190 and 191, show different forms of core, all or any of which have the same peculiar property as the double-coned core, all being made with the greatest mass of metal in the middle, and gradually tapering or decreasing to almost nothing at their ends, the biconical core, however, being the best of all.

The action of the Pilsen lamp with the coned core is the same when placed in a horizontal, or any position.

The uniform action of this peculiar shaped iron core is due to the equal and opposite magnetic effect which appears as the result from the decrease of the mass of iron in one solenoid being compensated for by the increase of its magnetic action, and *vice versa*, and it is this most interesting feature which constitutes the principal novelty in the Pilsen lamp.

Figure 192 of the diagrams shows a simple application of the biconical iron core and double coils. The top coil, M, is in the main circuit, the positive wire after passing round this coil being connected to the contact guide roller, *r*, and from thence through the frame and tube to the top electrode, and so through the arc to the negative wire, which is directly attached to the bottom carbon. One end of the shunt coil, M^1, of fine wire and high resistance, is connected to the wire M at the terminal at top, the other end of the shunt coil being connected to the bottom carbon-holder; the iron core is fixed inside a brass tube, which again slides inside another brass tube, round which the coils, M and M^1, are wound, the iron core being counterbalanced by the weight, W, suspended from a cord passing over the roller, R, so that the core is free to move up or down to any position. The two coils, M and M^1, are so regulated that, when the arc formed at the carbons is of exactly the proper length, usually two millimetres, the action of the coils upon the core is exactly balanced. Any alteration in the resistance of the circuits by increase of the length of the voltaic arc disturbs this balance, and the iron core with the top carbon attached descends and again restores the balance, and remakes the size of the arc to the predetermined length. This lamp is essentially an electrical lamp, as contrasted with mechanically regulated lamps, and as made is extremely simple.

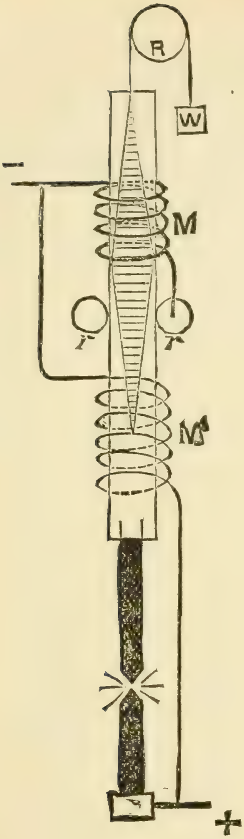

Fig. 192.

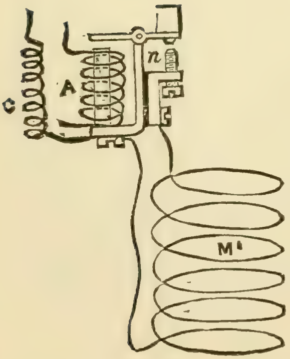

Fig. 194.

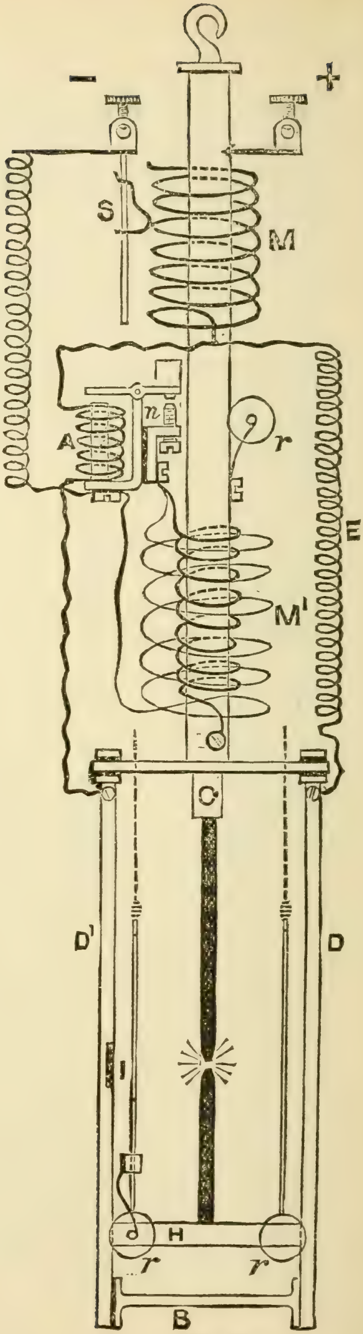

Fig. 193.

The theoretical examination of this combination of biconical core and two solenoid coils confirms its practical action. The following examination and formulæ are taken from the *Zeitschrift für Angewandte Elektricitätslehre*, No. 12, 1881 (see figure 192.)

Let S represent the pull of the main coil, M,
and S^1 that of the shunt coil, M^1.
R the force pulling the carbons together, allowing for the resistance of friction caused by the movement.

The weight of the core being counterbalanced as before mentioned, the inertia of movement is the same in any position.

Let J represent the current passing in the main circuit,
and J^1 the current passing through the coil M.
J^2 the current passing through the coil M^1,
and o — the resistance of M.
a — the resistance of M^1,
y — the resistance of the carbons, and
x — that of the light.

It is to be calculated what function x is of the other variables.

The following formulæ have been determined :—

$$S = A J^1 \qquad . \quad . \quad . \quad . \qquad 1.$$

$$\text{and } S^1 = B J^2 \qquad . \quad . \quad . \quad . \qquad 2.$$

A and B being constants of the functions of the magnetic movements of the coils.

Further,

$$J = J^1 + J^2 \qquad . \quad . \quad . \qquad 3.$$

$$\frac{J^1}{J^2} = \frac{a}{x + y} \qquad . \quad . \quad . \qquad 4.$$

from 3 and 4 follow

$$J^1 = \frac{J}{1 + \frac{x+y}{a}} \qquad . \quad . \qquad 5.$$

$$J^2 = \frac{J}{1 + \frac{a}{x+y}} \qquad . \quad . \qquad 6.$$

$$S - S^1 + R = o \quad . \quad . \quad . \qquad 7.$$

If we substitute the values found as above for S, S¹ and J, J² in the examples 1, 2, 5, 6, into and for 7, the result would be

$$A \frac{J}{1 + \frac{x+y}{a}} - B \frac{J}{1 + \frac{a}{x+y}} + R = o.$$

From this

$$\frac{A}{1 + \frac{x+y}{a}} - B \frac{J}{1 + \frac{a}{x+y}} + \frac{R}{J} = o.$$

After that,

$$\frac{A\left(1+\frac{a}{x+y}\right) - B\left(1+\frac{x+y}{a}\right) + \frac{R}{J}\left(1+\frac{x+y}{a}\right)\left(1+\frac{a}{x+y}\right)}{\left(1+\frac{x+y}{a}\right)\left(1+\frac{a}{a+y}\right)} = o.$$

Further,

$$\left(\frac{x+y+a}{x+y}\right)\left[A - \frac{B}{a}(x+y) + \frac{R}{a\,J}(a+x+y)\right] = o.$$

If we put

$$\left(\frac{x+y+a}{a+y}\right) = o,$$

then $x = -y - a.$

This result is of no value, being negative, for x can have a positive value only. We, therefore, put

$$A - \frac{B}{a}(x + y) + \frac{R}{a\,J}(a + x + y) = o$$

then
$$(x + y)\left(- \frac{R}{a\,J} + \frac{B}{a} \right) + A + \frac{R}{J} = o$$

then
$$x + y = \frac{\frac{R}{J} + A}{- \frac{R}{a\,J} + \frac{B}{a}}$$

and
$$x = a\,\frac{A\,J + R}{B\,J - R} \quad \cdots \quad \cdots \quad \cdots \quad 8.$$

The right side of example 8 contains the two variable elements J and y, and the resistance x of the arc in that case depends upon the current flowing. If we put $y = o$, viz., when the carbons are all burned, then x will be increased in value by the elimination of the resistance of y, and most probably the length of the arc would be increased a little. The correction for this is made by altering the true cone of the core a little only, so that, in fact, examples 1 and 2 are not quite correct. The powers of S, S^1 are also by this alteration made partly depending upon the position of the core.

We can therefore describe example 8 as

$$x = a\,\frac{A\;J + R}{B\;J - R} \quad . \quad . \quad . \quad . \quad 8a.$$

We have still to eliminate the variable element J from the right side. We know from practical test of the friction of the wheel R that this variable element can only possess small value when the lamp is otherwise well constructed and worked: from this it is to be seen that the alteration of the current passing, and the friction, cannot have much effect upon the arc, still we can eliminate it altogether by making R equal to nought, that is, by making W equal to the weight of the iron core minus the friction-resisting motion. After that equation 8a becomes

$$x = \frac{a\ \mathrm{A}}{\mathrm{B}} \quad . \quad . \quad . \quad . \qquad 8b.$$

x is therefore nearly absolutely constant.

The weights of the carbons during each stage of their burning are the same, through their shortening proportionally, and the attendant changing of resistance being compensated by the alteration of the iron core, which is very carefully attended to (we call special attention to this so as to avoid any mistake), the length of arc of such a lamp would therefore be constant. The arc length of a lamp of which x possesses a constant value is a function of the strength of the current: the length of the arc is of course altered by different carbons, we therefore either compensate their varying resistances or use one description only.

The example 8b can in practice be very well used: $\frac{x_2}{a}$ represents, for instance, the loss of current through the shunt circuit; $\frac{x_2}{a}$ therefore must be as small as possible. A good proportion is 0.04, now the resistance of the light.

With good strong light, each = 0.5 to 1.0 ohms.
" medium........ = 1.0 to 2.0 ohms.
" less........... = 2.0 to 3.0 ohms.
" dividing........ = 3.0 to 5.0 ohms.

As an example, let it be $\frac{x_2}{a} = 0.04$ and x_2 4 ohms, a therefore = 100 ohms.

Further, we can, as nearly as possible, for practical purposes, say $\frac{\mathrm{A}}{\mathrm{B}} = \frac{m}{n}$ if m and n represent the number of turns on the wire spools.

If *a* is rightly given above in the proper length, so is accordingly known the size or substance of the wire which has to be used. We can, therefore, take *m* to be the same, and with that all dimensions needed for the construction of the lamp are known, and a lamp of constant resistance can be made, a most important result for burning a number in one circuit.

Fig. 193 is a diagram of the electrical construction and connections of the Pilsen lamp as actually used. Fig. 194 is a diagram of the automatic cut-out electro-magnet.

The negative wire of the main circuit is connected to the terminal on top at the left, from thence it passes across to the main coil, M, by means of the sliding contact spring, S; after it has passed round the coilings of M, it splits into two circuits, one wire passes round the small electro-magnet, A, and is then connected to the rod, D^1 (insulated from the frame of the lamp), and so down to the contact roller, *r*, and lower carbon and holder, H. The other of the two split wires passes down through a resistance coil of iron wire, E, and is attached to the other rod, D (also insulated from the frame), and then to the lower carbon-holder by the contact roller, *r*. The positive wire enters at the right-hand top terminal, and makes direct contact with the frame and top carbon, thus completing the main circuit through the carbons and arc.

The shunt circuit is connected at the negative terminal, and passes through a comparatively thick german silver resistance coil, G, and then makes contact with the iron frame of the electro-magnet, A; from thence the wire is connected to a fine german silver wire coil of about 130 ohms resistance, wound on the outside of the shunt coil, M^1, the other end of this coil being connected to the contact screw, *n*, and to one end of a comparatively thick copper wire of low resistance which is coiled inside the german silver wire on M^1; the other end of this inside copper wire coil is attached to the metal frame of the lamp, and so completes the shunt circuit, the object of the supplementary resistance, G, being to make up a total resistance with the copper coils inside M^1 about equal to the lamp when burning, and to avoid heating when the main current all passes through that shunt or partial shunt circuit.

There are some interesting and novel electrical details in this lamp. The arrangement for altering the length and number of convolutions of the wire on the main coil, M, is new, and is effected as follows, viz. :—After the wire is all coiled on M (Fig. 193 and Fig. 195), the insulation is scraped off a strip ½ in. wide all down the outside of the coil, leaving a ridge of bare copper wire; the connection is made through the contact spring, S, sliding up and down the fixed rod, and pressing against the exposed wire, the bottom end of the rod being insulated; by moving S up or down, the length of the coil, M, may be increased or diminished at will, and consequently the pull of the coil M. This affords a ready method of adjusting the length of the arc, and also regulating the balance should the carbons vary in the resistance. The resistance of the main coil, M, is ·025 of an ohm, and the difference of resistance afforded by the sliding contact, S, when at extreme ends, is from ·023 to ·025 of an ohm.

The use of the small electro-magnet, A (Figs. 193, 194 and 195), for automatically short-circuiting the high resistance shunt coil on M^1, when the carbons are all consumed, or when there are no carbons in it at all, is also interesting. As before described, a split wire from M passes through this electro-magnet. The iron frame of A is made of a bell-crank shape, so that the armature at the top is a prolongation of the bottom pole, thus utilizing both poles. This armature is pivoted in the centre, and on its outer end is weighted to overbalance and make contact with the adjustable contact screw, *n*, fixed to an insulated bracket at side of the frame of A. One end of the fine wire shunt coil on the outside of M^1 is connected to the wire of G, and to the metal frame of A, at bottom, and the other end to the copper shunt coil and insulated bracket and contact screw. When the lamp is not burning, the armature of A makes contact with the screw, *n*, and short-circuits the fine wire coil on M^1, the main current then passes through the thick supplementary resistance wire, G,

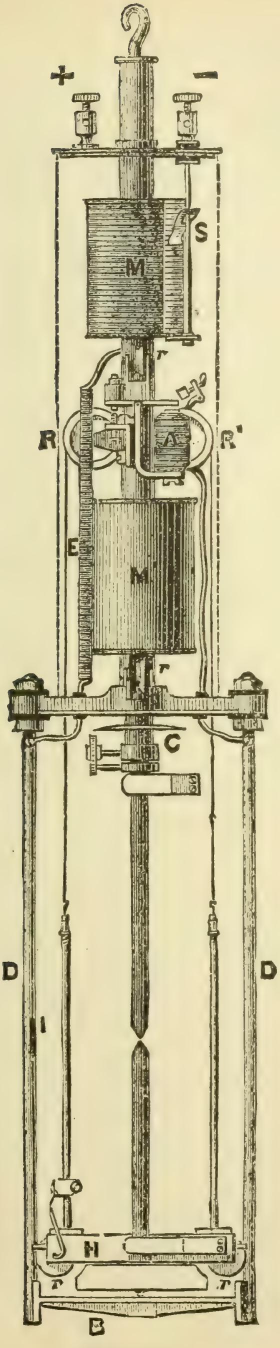

Fig. 195.

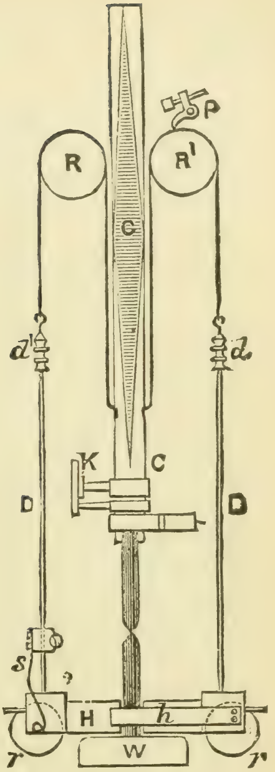

Fig. 196.

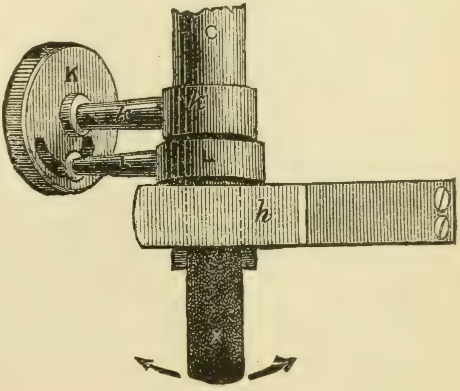

Fig. 197.

and the inside copper coil of M^1. When the lamp is burning, the main current passes through A, and attracts the armature, and retains it, thus breaking the contact at *n*, and adding the fine wire coil of M^1 to the shunt circuit, which then balances the lamp.

When the carbons are all consumed, the electro-magnet, A, automatically cuts out and breaks the arc: this is done by inserting a small piece of an insulating material in the guide rod, D^1, at I. When the bottom carbon-holder, H, rises to the insulated insertion, I, the roller, *r*, on that side becomes insulated from the rod D^1, and the electro-magnet, A, is cut out of the circuit, the armature is released, and the weighted side remakes contact, and short-circuits the german silver coil on M^1. The top coil then preponderates and pulls the top carbon up, and so completely separates the carbons, and breaks the arc; the current then passing through the thick shunt coil and wire, G. During this latter operation the supplementary wire and split circuit, E, keeps the circuit through the arc (which would otherwise be broken by the insulation at I), and thus allows the main coil M, to separate the carbons, and prevent the burning of the metal holders, H and *h* (Figs. 187, 188 and 189).

The mechanical construction of the Pilsen Lamp is also very good. The frame of the lamp (Figs. 195, 196 and 197) consists of a brass tube, mounted between two brass plates, with two iron rods, D^1 and D, joined across at the bottom by the stretching piece, B; the iron core C (Fig. 196), is fixed inside a brass tube, which again fits loosely in the tube of the frame, and is guided by contact rollers, *r* and *r*, so that it moves with very slight friction; the weight of the iron core, C, is counterbalanced by the bottom carbon-holder, H, and weight, W, the connection being made by means of the cords and rods, and the pulleys, R and R^1; the metal rods, DD (Fig. 197), being used in the vicinity of the arc. The carbons are fixed as shown, one to the core tube, C, and the other to the holder, H.

One of the pulleys, R^1 (Fig. 196), has very fine teeth cut in its outer rim, and a weighted pawl, or click, P, rests upon and gears into the teeth; the object of this being to restrain the cord which must in one direction rub over the pulley R¹, and thus serve to arrest the parting of the carbon when there are any fluctuations in the current.

The carbons are fitted and adjusted in a simple manner: they are inserted into the spring clips, *hh*. The bottom carbon and holder can be partly adjusted by altering the lengths of the two side cords: this is done by screwing or unscrewing the nuts, *d d*¹, attaching the cords to the rods. The top carbon can be adjusted to any position by the holder shown at Fig. 197. The spring clip, *h*, is attached to the collar and arm, L, and the two are pivoted at K, and are free to move laterally; above L is a fixed collar and arm, *k*, and on the end of that arm a milled head, K, is free to burn. K has an eccentric slot cut in its face, into which a pin projecting from the end of L is inserted. By turning the milled head, K, the arm, L, and carbon clip, *h*, are moved backward or forward, as may be required. The core tube, C, can also be moved round.

The lower carbon-holder, H, runs by means of the contact rollers, *r* and *r*, between the guide rods, D¹ and D, the contact being maintained by the spring, *s* (Fig. 196). Sometimes a permanent electrical connection is made by a loop of wire attached to the rods, D, and holder, H.

If a fixed focus lamp is required, the pulleys, R and R¹, are made double, one being twice the diameter of the other; the cord that passes over the larger pulley being connected to the top electrode, while the bottom electrode is connected to the cord passing over the smaller pulley, the different sized pulleys allowing the carbons to feed together exactly in proportion as they are consumed.

The top of the lamp with the coils is completely incased in a zinc cover box. The globe is put on from below in the hanging lamps (Fig. 198), and is supported on the ash pan which slides up and down the rod at the bottom. This is very convenient for putting in fresh carbons.

The apparent complication of the Pilsen Lamp, as made for

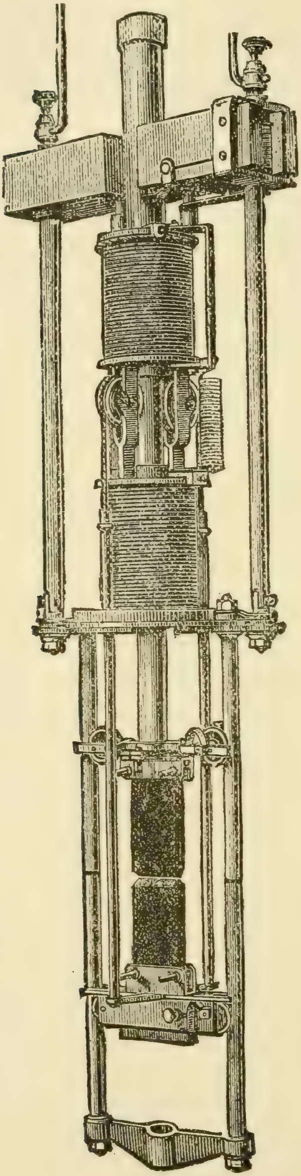

Fig. 198.

practical use (Figs. 193, 194, 195, 196 and 197), in contrast with the theoretical construction (Fig. 192), is really a simplification, inasmuch as a workman has no adjustment to make, and no screws to unloose, the electrical and mechanical refinements being specially introduced to render the lamp as nearly as possible automatic in its action.

Fig. 198 shows the Pilsen Factory Lamp, which has some novel features.

This lamp is made to burn 100 hours if necessary. The electrical connections are the same as those in the lamp shown in figures 192 to 197. The small control electro-magnet in this lamp is fitted in the top wooden frame at the right side, and is there out of the way of harm. The mechanical construction of this lamp is much stronger than the hanging lamp (Figs. 192 to 197): there are two sets of contact rollers, one set attached to the top and one set to the bottom carbon. The principal novelty in this lamp is the use of plate carbons.

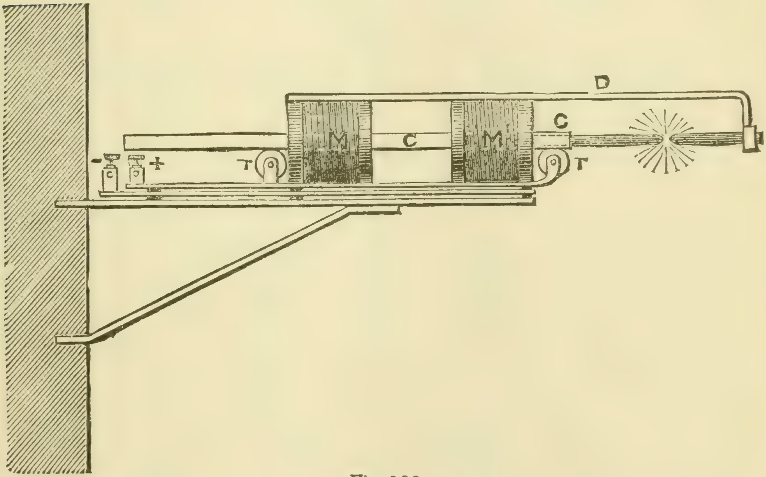

Fig. 199.

Some of these lamps have been in use in Mr. Piette's paper factory at Pilsen, and work remarkably well: they have proved very suitable for factory purposes, where a cheap and reliable light is required.

Fig. 199 shows a diagrammatic drawing of the Pilsen Horizontal Lamp. The iron core, C, is fixed inside a brass tube, and is supported and free to move upon the contact rollers, *rr*; one carbon is fixed to the end of the tube, C, and the other to the pivoted arm, D; the coils, M and M^1, are practically arranged in the same way as in the previously described lamp.

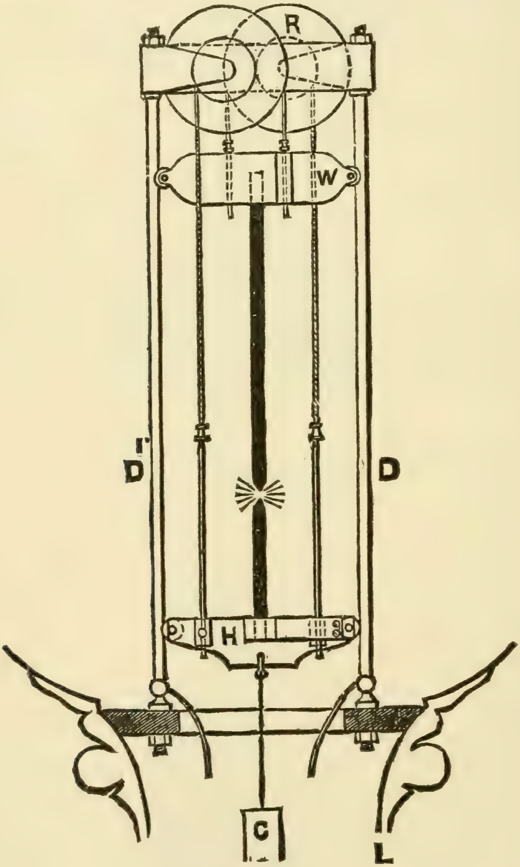

Fig. 200.

The special advantage of this form of lamp is that it can be used in low-roofed factories, close up to the ceiling. This lamp was shown constantly at work in the Electrical Exhibition at Paris, and burned remarkably steadily.

Fig. 200 shows the Pilsen Lamp adapted for street lighting. In this lamp the counterbalance of the iron core is reversed, and the coils placed at the bottom, and inside the tube of the top of the lamp; the side rods, D D^1, weight, W, holder, H, and rollers, R, with their cords, are, except for being reversed, the same as the hanging lamp described in reference to Figs. 192 to 197.

This special arrangement of the lamp allows the coils to be placed in safety, and avoids shadows on the globes.

The advantages claimed for the Pilsen Lamp are:

Its extreme simplicity.

Its almost perfect working.

A steady and white light, of good power.

The ease with which the carbons can be fitted.

It has a constant electrical resistance, enabling any number of lamps to be used in one circuit.

It has a continuous feeding movement.

Also automatic appliances provide for all practical contingencies; and a special and distinct advantage is, that it can be worked with almost any description of engine: the absence of all clutches and releasing gear enables the lamp to quickly adjust itself to variations of speed.

The Pilsen Lamp has been fitted in many places and with unqualified success, and was successfully exhibited in the Crystal Palace, London, six hanging lamps illuminating the Handel Orchestra. On the Continent the lamps have a very large sale, and give great satisfaction.

The six hanging lamps shown at the Crystal Palace were all worked in one circuit from a Schukert dynamo machine, revolving at 850 revolutions per minute, and driven by a Ruston and Proctor single cylinder portable steam-engine, with the ordinary governors. The current passing through the lamps was about 9 ampères, the electro-motive force of the current being about 400 volts, and the total resistance about 45 ohms. The candle-power of the Pilsen Lamp exhibited was 2,000 candles.

THE ARCHEREAU ARC LAMP.

The first self-acting regulator was made by Archereau in 1848, and his primitive apparatus, embracing the solenoid action, has served as a basis for numerous other combinations.

In Archereau's lamp, fig. 201, the upper carbon is fixed, and the lower carbon rests on a cylinder made half of iron and half of copper. This cylinder is placed in a solenoid, which is traversed by the current, and is kept in equilibrium by a counterpoise.

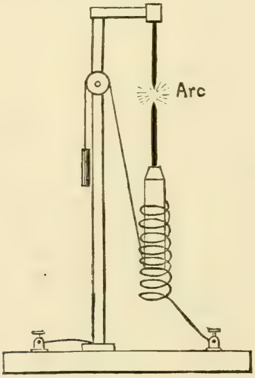

Fig. 201.

The action of the solenoid produces and maintains the distance of the two carbons by exercising a magnetic attraction on the iron rod which terminates the lower carbon, provided the proportions between the power of the solenoid, the weight of the rod, and the strength of the current are carefully established. This regulator is no longer used, because the luminous point was not constant, and it was difficult to regulate the action of the solenoid without causing a rupture of the arc.

THE JASPER ARC LAMP.

Fig. 202 represents the Jasper regulator. The negative carbon holder B is formed of a copper tube, ending in a hollow cylinder of soft iron. In the middle the tube B is pierced with a longitudinal slit, wide enough to allow a grooved pulley, E, to pass; around this pulley is wound a cord which descends in the axis of the tube B, and carries a weight F, that keeps it stretched. This weight abuts upon a traverse piece in such a way that, when the cord is wound up, the weight in rising lifts the carbon holder. The grooved pulley is fixed on a small draw, on which is also placed a second grooved pulley having a diameter double that of the former. On the latter is wound a cord attached to the lower extremity of the positive carbon holder A, and it also carries a counterpoise. It will be seen that, by the direction in which the cords are wound, the weight of the positive carbon-holder tends to raise the negative carbon-holder, and that this will move through only half the distance of the former. This difference corresponds to the unequal wear of the carbons. The positive carbon-holder is formed of a copper tube A, furnished with a clip to which the carbon is attached. The carbon is held securely in place by a locking screw.

The negative carbon-holder carries a pendent rod L, terminating in a small piston which can move within the tube D, filled with mercury. The diameter of the piston is less than that of the tube, so that when the piston moves down by the motion of the carbon-holder, the mercury passes from one side to the other of the piston by the narrow annular space. This acts as a very efficient brake, and prevents any sudden action which would show itself in irregularity of the light. On the tube C, is wound an insulated copper wire forming a solenoid, and intended to

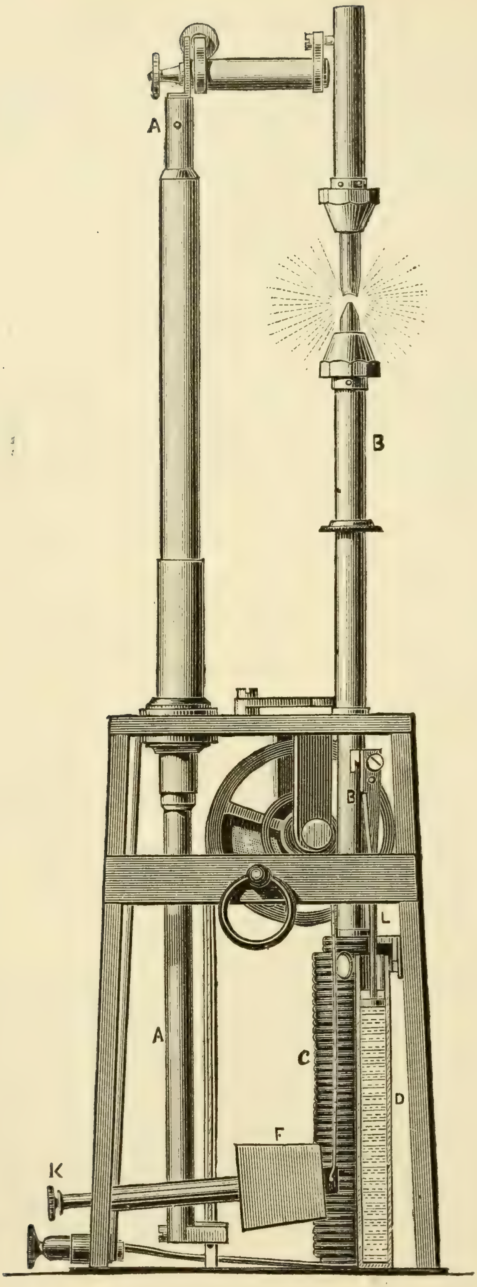

Fig. 202.

produce the separation of the carbons, and to counterbalance the effect resulting from the weight of the positive carbon-holder, as in Archereau's regulator.

When at rest the carbons are in contact. At the moment when the current passes, the solenoid attracts the iron core of the lower holder and maintains the carbons at the proper distance. When the arc is lengthened, the current is weakened, and the carbons acted on by the weight of the holder A are drawn slightly nearer to one another. The counterpoise F acts in an opposite sense to the holder A, since, by the winding of the cords, it tends to produce a withdrawal. The adjustment is, therefore, easily obtained by the displacement of the weight F. The stronger the current, the nearer the weight F must be to the point where the cord is attached.

The action of the solenoid on the carbon-holder B is not the same at the end as at the beginning. This difference of action is compensated for by the small counterpoise, which is regulated by its distance from the centre. At the beginning the latter counterpoise has no action; at the end its weight is added to that of the weight F, to counterbalance the action of the solenoid.

THE REYNIER ARC LAMP.

M. Reynier's lamp consists of two carbon-holders, the upper one of which is fixed, and the lower one is mounted on a soft iron rod placed within a solenoid, the action of the latter being balanced by a coiled spring. As soon as the current passes into the apparatus, the iron rod is drawn downward in the solenoid, and descends until the arc reaches its normal length. In proportion as the carbons are consumed, the iron rod ascends in gradual stages, which are equal to the lengths of burned carbons, so as to maintain the length of the voltaic arc constant.

THE SCHUCKERT ARC LAMP.

In the Schuckert lamp the upper carbon is raised by a split clutch forming the core of a solenoid. This core is suspended by a lever, adjustable by a spiral spring, and as soon as the current traverses the solenoid, the plunger is drawn upward, closing round the carbon and raising it. The current is led to the carbon by two copper contact rollers. The action of the lamp depends upon the principle of the derived current.

THE GAIFFE ARC LAMP.

The Gaiffe lamp is represented in figure 203. In this apparatus the action of the solenoid is produced in a somewhat different manner from the preceding ones. The two carbon-holders, H H′, are movable, and are so arranged as to keep the luminous points stationary. For this purpose their motion is controlled by two racks, K U, which engage two wheels M′ O, of unequal diameter, and moved by a simple spring barrel on the axle of which they are fixed. This barrel is wound up by the mere separation of the carbon-holders, which are, however, perfectly balanced and turn between sets of rollers. The lower carbon-holder is terminated by an iron rod, K, to which is attached a rack, and this rod is placed within an electro-magnetic bobbin, L, with a coil increasing in diameter from its upper to its middle part, in order to compensate for the unequal action of the spring barrel through the whole range of this movement. Finally, a small wheel, R, connected by the wheels M′ O, and another to the wheel M, gives the means of simultaneously acting on the two racks, so as to raise or lower the luminous point.

In the normal state the carbons touch each other, and when the current traversing them excites the coil, the lower carbon-holder is lowered at the same time that the upper one, H V I, is raised, and this effect is continued until the attractive force of the coil balances the resistance of the spring barrel, and thus a voltaic arc is produced. Of course the length of the arc depends upon the tension of the spring in the barrel, and this can be regulated by a screw. So long as the arc remains under the same conditions of resistance, the effect is maintained; but the moment the resistance increases on account of the consumption of the carbons, the power of the spring prevails over the electro-magnetic action, and the carbons are brought nearer together until a condition of equilibrium is again attained, and the same thing goes on until the carbons are entirely consumed.

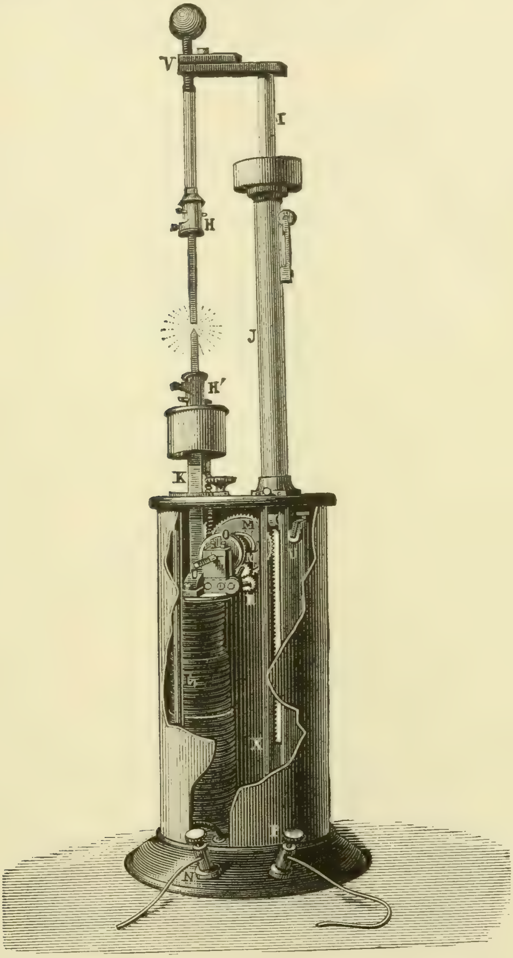

Fig. 203.

The small mechanism fitted to the wheels of the racks allows the luminous point to be raised or lowered, by means of a key, without the lamp going out, and this is necessary in optical experiments in order to properly centre the light.

THE DE MERSANNE ARC LAMP.

The De Mersanne lamp, represented in figure 204, which was invented to enable straight carbons to supply an electric light for at least sixteen hours consecutively, is essentially formed of two slide boxes B B′, fixed on a strong upright stand of cast iron. Through these slide the two cylindrical carbons C and C′, each 30 inches or more in length, moved by a regulated action. In order that the carbons may be adjusted to have their points in the same vertical line, the boxes are capable of turning a little vertically, and the upper one can also be turned horizontally. The sliding system of both boxes consists of four grooved rollers, two of which are connected with two ends of a lever, and pressed against the carbons by a spiral spring *v*. These rollers serve as guides, and the other two, of larger diameter and with a roughened surface, act as the movers of the carbons. For this purpose these are set in motion by wheels fixed on an axle, connected by mitre wheels with a vertical shaft A A. This shaft, being capable of turning in either direction, according to the action of the regulating apparatus, can make the carbons approach to, or recede from, each other. The carbons are supported and protected outside of the boxes by inclosing tubes.

The regulating apparatus is placed in a case below the slide box B′ of the lower carbon. It consists in the first place of clockwork driven by a spring barrel, which will act for 36 hours without attention, and by an electro-magnet, E, forming part of a derived circuit from the two carbons; and in the second place, of another electro-magnet, M, interposed in the same derivation, and acting on the box B' of the lower carbon in such a manner as to separate the carbons when they come into contact. When the apparatus is not in action, the carbons are generally separated by a greater or less interval; but as soon as the circuit is closed through the apparatus, the two electro-magnets are excited, for the current then wholly passes through

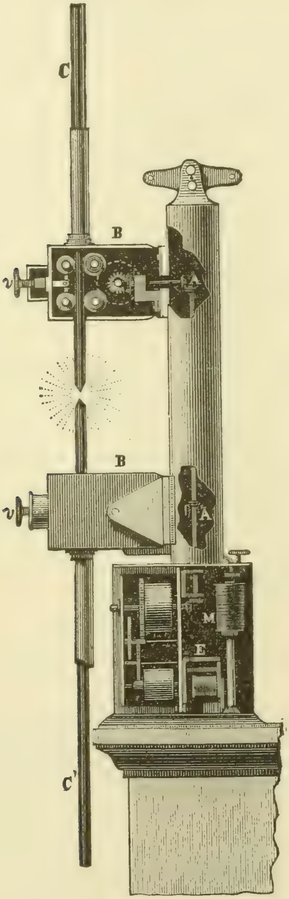

Fig. 204.

the derivation, and the clockwork is liberated, while the lower holder is so inclined exactly as to bring the two carbons one over the other. The advance of the carbons takes place slowly, and when they come into contact, the current, finding a more direct path, abandons the derivation and the electro-magnets, and passes almost entirely through the circuit of the carbons, which then glow, and immediately supply the voltaic arc. The electro-magnet M having become inactive, the box B′ of the lower carbon-holder is slightly inclined forward, and by this causes not only the disjunction of the carbons, but also a sufficient separation of their points in consequence of the action produced on the wheels by the movement of the box. The lamp is thus lighted; but in proportion to the consumption of the carbons, the resistance of the light circuit increases, and the current, passing with more intensity into the derivation, soon becomes sufficiently powerful to release the clockwork that brings the carbons together, until the current has regained its full intensity in the light circuit. Things go on in this way until the carbons are entirely consumed.

It will easily be understood that with this arrangement there is no limit to the length of the carbons, since it may exceed that of the apparatus, and without their requiring any particular position. Their forward movement takes place as if they glided between the fingers of two hands, pushed towards each other by two thumbs guiding their progress.

THE BURGIN ARC LAMP.

The Bürgin lamp is represented in figure 205.

The principle of the lamp is very simple: the two carbon-holders tend to approach each other continuously by the influence of a spring barrel or a counterpoise; but they can obey this tendency only when a check controlled by an electro-magnetic action permits the passage of the chain or chains which support the carbon-holders, so that, according as the current is more or less energetic, there is motion or rest in these carbon-holders. This result is obtained by means of a large wheel, R, which carries on its axle the pulley C, on which is wound the chain supporting the lower carbon-holder. The axle of the wheel rests on a piece of iron, A A, fixed to a jointed parallelogram, and serving as the armature of an electro-magnet, E, connected with the light circuit. A spring brake, F, presses on the circumference of this wheel, and is sufficiently bent to prevent the wheel from turning when the latter is at the proper height, that is to say, when the armature A is at its greatest approximation to the electro-magnet E; but when, in consequence of the weakening of the current, this armature is at a greater distance, the wheel, by dropping with the armature, withdraws from the brake, and is then able to turn by the effect of the

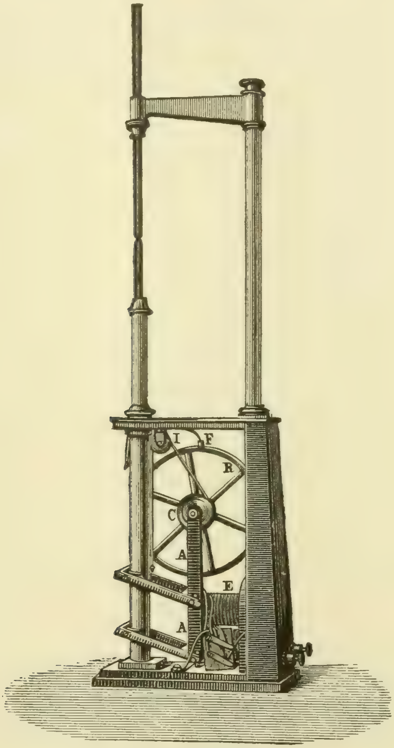

Fig. 205.

weight of the lower carbon (or of a spring barrel attached to this carbon-holder), acting through the chain which is wound about the pulley C. Thereupon the lower carbon-holder rises, and the current, resuming its energy, quickly produces a fresh engagement of the wheel, which checks the rise of the carbon at the proper instant. The slight movement of the attracted armature A, when the carbons are in contact, suffices to allow the passage of enough chain to bring about the separation of the carbons when the circuit is closed.

The upper carbon is fixed, and therefore the luminous point changes its position, a thing of no consequence for ordinary illumination; but for experiments of projection, the two carbons must be so arranged as to move simultaneously in the proportion of 2 to 1, and for this purpose Bürgin fixes two carbon-holders to two chains, which are wound upon two pulleys of unequal diameter, mounted on the axis of the large regulating wheel, so that each movement of that wheel causes a double displacement of the carbons. An adjusting screw attached to the brake allows the apparatus to be made more or less sensitive. It is the weight of the upper carbon-holder which brings the carbons together, and the attractive action of the electro-magnet first determines their separation in order that an arc may be formed, and afterward stops them so as to maintain their due interpolar distance.

THE VON HEFNER ALTENECK ARC LAMP.

Figure 206 represents the Von Hefner Alteneck arc lamp, manufactured by Siemens, which is much used in England and Germany. It can be lighted automatically, and the two opposite actions required for the separation and approach of the carbons are determined by the weight of the upper carbon holder and by the electro-magnetic vibration of a rocking lever which acts on a clockwork mechanism driven in the opposite direction by the weight of the carbon holder. This mechanism is composed of four wheels, and it is on the last wheel, I, furnished with a ratchet and a fly with wings, that the vibrat-

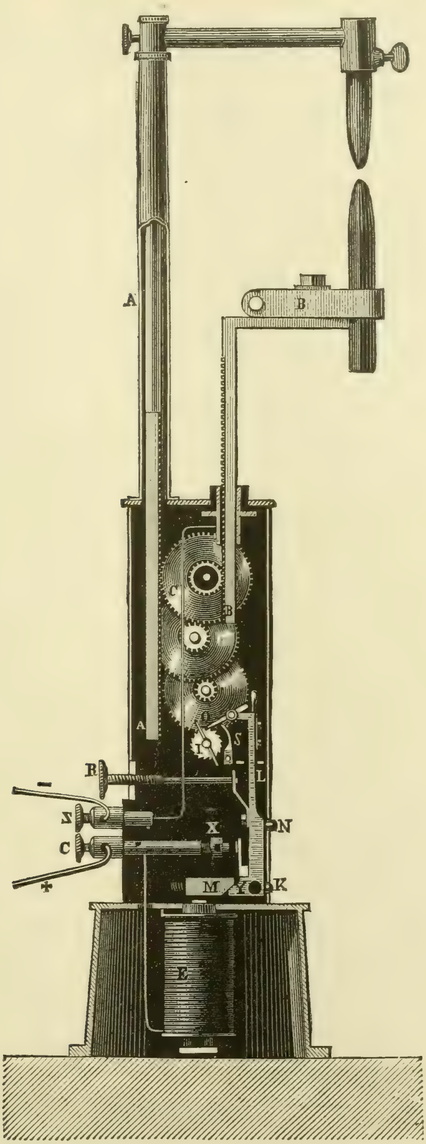

Fig. 206.

ing electro-magnet acts. This last is formed of a bent lever L, jointed at Y, and carrying at M the armature of the electro-magnet E. This is the principal organ of the apparatus, for on one side it carries a contact piece which forms with the stud X the vibrating circuit-breaker, and in the second place the antagonistic spring of the system, the tension of which is regulated by means of the screw R, and finally the driving and stopping catch Q, which acts on the clockwork mechanism by means of the ratchet wheel I. A fixed piece, S, supports the end of this catch, in order to liberate the wheel I, at a suitable inclination of the lever L. Finally, a screw K, which passes through the case of the lamp, allows the distance of the armature to be properly adjusted to the current employed, and a small addition, N, which also projects from the case, shows whether the electro-magnetic system is properly vibrating. The wire of the electro-magnet E is, moreover, connected with the mass of the apparatus, in order that the current which passes through and illuminates the carbons may be derived through the circuit-breaker at each attractive movement of the armature, and produce the vibration of the lever L, by closing a short circuit.

The action of this apparatus is very simple. When a current passes through the electro-magnet E, the catch Q is withdrawn from the wheel I, and the upper carbon-holder, by weighing on the wheels of the clockwork, sets them going until the carbons guided by racks engaging these wheels are brought into contact. But if under these conditions the generator is put into communication with the lamp by the binding screws Z and C, the current traverses the electro-magnet E, the mass of the apparatus, the upper carbon-holder, the lower carbon-holder, and returns to the generator by the communication connecting this with the binding screw Z; the carbons then glow at their point of contact, the electro-magnet becomes active, and the catch Q, by acting on the ratchet wheel I, causes it to advance one tooth, by which the carbons are separated. But in this movement a contact is set up at X, between the lever and the screw C, and the current, finding less resistance in passing by that path than through the electro-magnet E, in a great measure leaves the latter; then the armature, being no longer sufficiently attracted, causes a backward movement of the lever L, which again withdraws the catch Q, destroys the contact at X, and brings about a new attraction of the armature, involving a new movement of the wheel I, and as these alternating motions are more rapidly effected than that which results from the setting in motion of the wheels by the action of the upper carbon holder's weight, the carbons are soon sufficiently apart to produce a voltaic arc of suitable size, which increases in length in consequence of the consumption of the carbons; but when their distance apart becomes too great, the intensity of the current becoming too weak, is unable to cause the attraction necessary for the action on the wheel I, and then the wheels can turn freely, causing thereby the approach of the carbons, which goes on until the current has regained an intensity sufficient to again produce the effects we have already studied. By a suitable adjustment of the screws R, K, and Z, the double inverse action we have just examined may be made very regular. But this adjustment is very delicate, and that is perhaps an inconvenience of the system.

The apparatus is also provided with two other systems of regulating screws, one of which moves the two carbons and the luminous point without extinguishing it, and the other allows one of the carbons to be displaced. Finally, screws attached to the upper carbon holder give a means of easily fixing the carbons with regard to each other, so as to supply a diffused or a condensed light. Two small bull's-eyes in the side of the lamp allow the action of the delicate parts of the mechanism to be observed, and the effects of the regulator to be noted.

In order that the generator of light may work always under the same conditions, whatever may be the variations in the circuit external to the lamp, Siemens has interposed in the circuit a regulator of resistance, consisting of an electro-magnet with a thick wire, the armature of which acts in the manner of a relay on a contact which, when the armature is not attracted, has the effect of introducing into the circuit a derivation with a resistance nearly equal to that of the voltaic arc. With a suitable regulation of the antagonistic spring, the derivation is therefore substituted for the voltaic arc whenever the resistance of the latter becomes so great that the armature is no longer retained. This is what happens not only when the lamp is put out or withdrawn from the circuit, but also when very great variations occur in the working of the lamp. The helix forming the derivation is placed in a tin vessel filled with water to prevent the wire from becoming too hot during long interruptions of the current, such as those required by replacing the carbons.

THE SIEMENS ARC LAMPS.

Mr. Siemens has invented several forms of lamps, among which are the following: Figure 207 represents a form in which the carbons, C C, are separated by the rod, R, which is

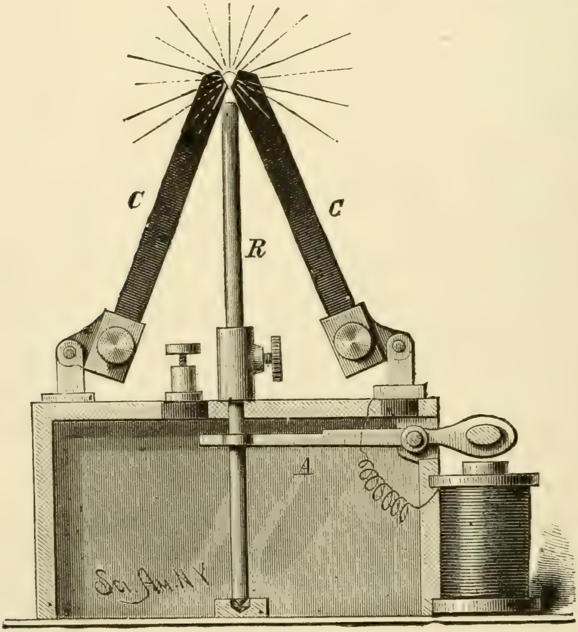

Fig. 207.

moved by means of the lower arm, A, which is set in action by the electro-magnet, E. When the current passes through the electro-magnet, E, and the carbons, C C, the rod, R, which is made of a refractory substance, thrusts the carbons apart. If the current should decrease in strength, the carbons fall together again, and the current is not broken by any similar lamp on the circuit failing to perform its function.

In figure 208 one carbon is set in oscillation or vibration by means of the lever arm, which is terminated by an iron cylinder, which forms the movable core of the electro-magnet, E. This carbon has to vibrate merely 32 times a second to cause the appearance of a steady light at the point, P. This lamp also admits of many lights in the same circuit.

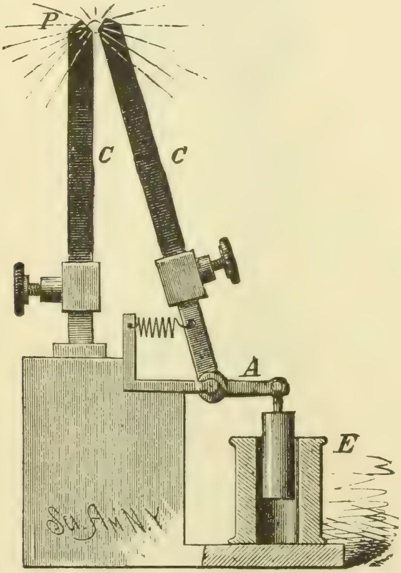

Fig. 208.

Figure 209 represents another form of the same idea. The upper carbon falls gradually upon the lower one, which is set into vibration by means of the lever arm, **A**, which is set in action by the electro-magnet, E. The lower carbon moves so quickly that the upper carbon, which is forced down merely by its own weight, cannot sympathize with it, and a small voltaic arc is therefore produced at P. The fluctuations of this arc are so rapid that they are said to produce no apparent alternation in the light.

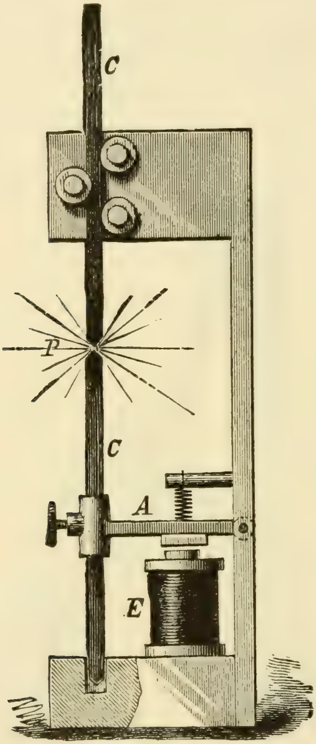

Fig. 209.

THE RAPIEFF ARC LAMP.

The Rapieff lamp is represented in figure 210, the carbons of which are, *a a′*, *b b′*. The voltaic arc is produced at C, between the upper and the lower pairs of points. As the carbons are consumed, they slowly move nearer to each other in each couple, under the influence of a counterpoise w, which, through the cords and the pulleys W $f\ h\ d\ a'\ a\ e\ g\ d'\ b'\ b$, pushes the sticks of

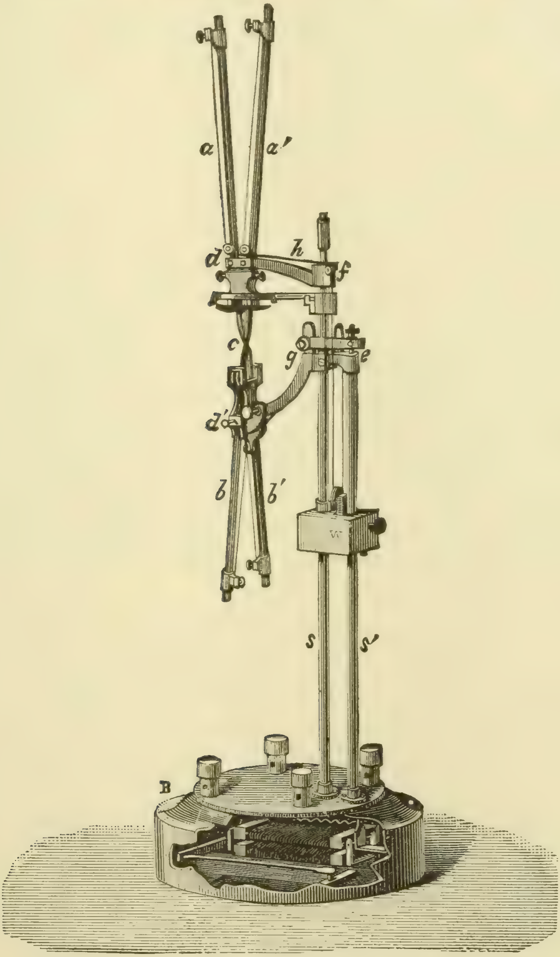

Fig. 210.

carbon against each other. This counterpoise is guided in its course by two columns, $s\ s'$, which at the same time serve as conductors for transmitting the current to the two systems of electrodes *a a′*, *b b′*, supported also by the two metallic arms *d h*, *d′ g*. As the upper carbons are to be connected with the positive pole, they are of course longer than the lower. This arrangement is completed by an electro-magnetic system inclosed in the base of the apparatus; and its office is, when the current passes and the four sticks of carbon are in contact, to separate the two systems to the distance necessary for the formation of the arc. This effect is produced by means of a cord attached to the electro-magnetic armature, which cord, passing within the column S, acts on the arm *d′ g*. A reflector of a cup shape, either of silvered copper or of porcelain, is fixed a little above the point of contact of the carbons, and adjusting screws enable the luminous beams to be turned in any required direction.

With carbons twenty inches long and one quarter of an inch in diameter, the light supplied by the lamp lasts for ten hours. This light may be reckoned at 100 or 120 gas jets, or at 1,000 candles; but with smaller patterns one may be obtained not exceeding 5 gas jets. The inventor has also constructed lamps in which the preceding arrangement is reversed, in order that they may be hung from the ceiling. According to him, the resistance of the arc does not exceed 3 ohms.

In another arrangement Rapieff combines the action of the voltaic arc with the luminous effect of a piece of kaolin placed above the arc. The four carbons are then arranged so as to form the four edges of a pyramid broken off at its summit, where a kind of bell of kaolin is placed, like the extinguisher of a lamp, and this when glowing increases the illuminating power. The carbons are Carré's, and a Gramme machine is the generator. With this machine 10 lamps of the first described pattern may be lighted by placing them in the same circuit.

The great advantage claimed for this lamp is that it will go a whole night without a renewal of the carbons; its intensity is always constant, even when the carbons are burned very low, and in this respect the lamp is preferable to the Jablochkoff candle, for in this the current increases in energy as the candle burns, on account of the decrease in the length of carbon the current has to traverse, while in the Rapieff lamp that length is always the same.

In order that the extinction of one lamp may not cause that of other lamps, Rapieff arranges the electro-magnet that separates the carbons in such a manner that it acts as a commutator. When the current passes through the electro-magnet, the commutator is not brought into action, and the circuit is completed through the lamp; but when this is extinguished or withdrawn from the circuit, the electro-magnet in question becoming inactive, causes the current to pass through a derivation in which a resistance equal to that of the lamp circuit is introduced, and the circuit of the other lamps is not interrupted thereby. This effect is attained by means of a second armature, which, being attracted when the current passes, acts as a keeper, thus increasing the electro-magnetic action exercised on the lamp, and sets the commutator in action, when the current no longer passing, the armature yields to the antagonistic action.

In a new pattern, Rapieff has replaced the upper carbons of the regulator by a large piece of carbon, which, as in Werdermann's lamp, does not burn. It is this form that is now most employed.

THE CARRÉ ARC LAMP.

Carré's lamp, represented in fig. 211, is only an ingenious improvement on Archereau's and Gaiffe's regulators. As in those, the electro-magnetic action is founded on the attractive effects of solenoids, but these effects are by an ingenious arrangement very much magnified, and the mechanical action is produced by clockwork acting on two racks, D, E, fixed to the carbon-holders, and controlled by a detent brought in action by the electro-magnetic system.

This system is formed of two coils B, B′, having their axes slightly curved, and into these pass the ends of a soft iron core A A, bent into an S shape, and turning at its middle part about the centre C. A double set of antagonistic springs, *r*, *r*′, regulated by the adjusting screw V, allows the force opposing the attraction of the coils to be suitably adjusted, and a rod, *t*, fixed to the magnetic core, acts on the detent of the clockwork. The motion of the wheels causes a forward movement of the two racks in the

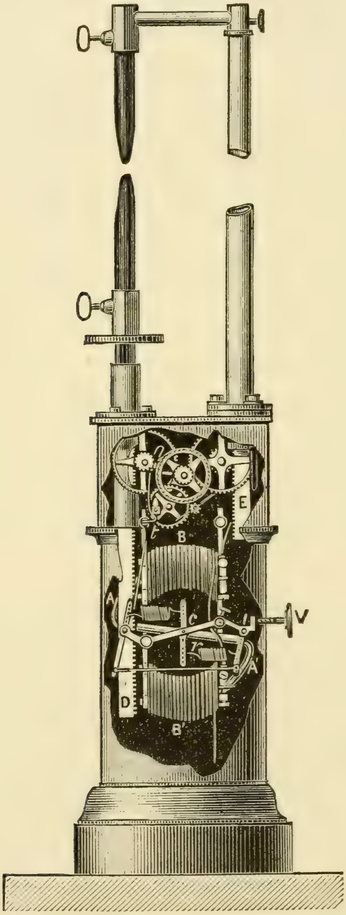

Fig. 211.

proper proportion for keeping the point of light stationary. The light current passes through the two coils, and according as its strength varies, the iron core is more or less attracted within the coils, a sufficient decrease causing a release of the detent, whereupon the approach of the carbons ensues.

In this system, as in those of Archereau, Gaiffe and Jasper, the increase of the current has the effect of separating the carbons from each other, and the clockwork brings them nearer together; but as under these conditions the path of the movable piece in the electro-magnetic system is considerable, and as the attractive effect is much less sudden than in the case of electro-magnets with turning armatures, the separation of the carbons are produced freely and without oscillations.

THE SEDLACZEK AND WIKULILL ARC LAMP FOR LOCOMOTIVE HEADLIGHT.

The principal difficulty in the use of the ordinary arc lamp for the headlights of locomotives has been that the jarring of the engine while in motion affects the regulating mechanism, so

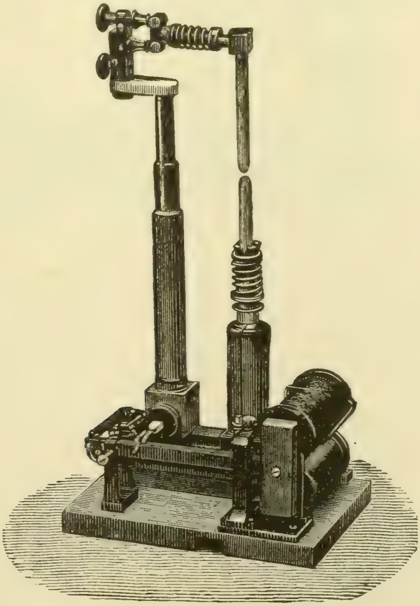

Fig. 212.

that the light is rendered extremely unsteady or is extinguished. This defect does not exist in the regulator shown in fig. 212, the carbons being held in position by pistons acted on by hydraulic pressure.

The pistons, *a* *b*, fig. 213, are of different diameters, the smaller one, *a*, being heaviest and connected with the positive carbon. The relative size of the two pistons is such that when the piston, *a*, falls of its own gravity, the piston, *b*, rises half the distance.

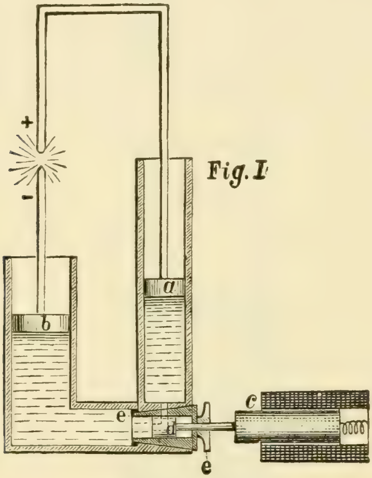

Fig. 213.

The regulation of the motion of the pistons is effected by enlarging or contracting the opening between the two cylinders. This is done by opening or closing a piston valve which is controlled by an electro-magnetic helix in the circuit or by a centrifugal governor.

When the electro-magnet is made weaker by the weakening of the current following burning away of the carbon, the piston *a* is moved back by the action of a spring, the communication is established again, and the carbons approach each other. By another position of the valve the fluid passes through a larger hole to allow a quicker movement of the pistons when new carbons are to be put in.

Instead of using an electro-magnet, the regulation of the arc can be secured also direct by the motion of the machine itself. For this purpose the shaft is connected with the piston, *a*, by means of a centrifugal governor, *f*. When the machine starts, the piston valve, *d*, is pulled out by the governor, and first closes the passage against the piston, *a*; in further pulling out the arc is established by drawing the liquid after it, and thus lowering piston, *b*. The burning away of the carbon increases the speed of the engine and machine, and a further pulling out of the piston valve takes place, until a second opening allows the communication of the fluids as soon as the arc becomes too long. Then the carbons approach each other, the machine runs slower, the governor pushes the piston back and closes the opening again.

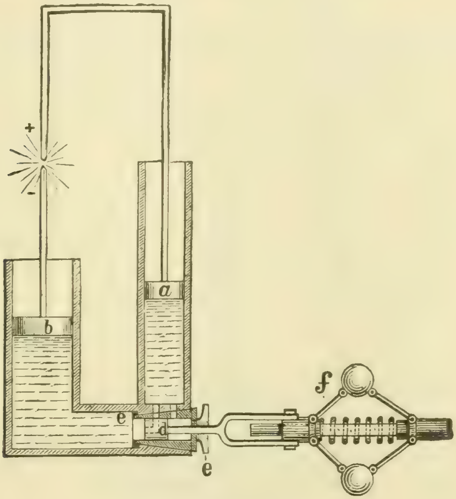

Fig. 214.

As the fluid between the two pistons cannot be compressed, and as no vacuum can be formed, the lamp burns well in spite of the heaviest shocks. We are informed many trial trips have been made on the Crown Prince Rudolf Railway in Austria, with the greatest success. The lamp was fed by a dynamo machine of S. Shuckert, of Nuremberg, driven by a Brotherhood three cylinder engine.

THE THOMSON ARC LAMP.

This lamp is designed to be used in series or singly. It consists of a metal frame supporting at the bottom the holder for the globe and lower carbon, which is insulated from the frame.

Fig. 215 shows its general appearance. The upper carbon is

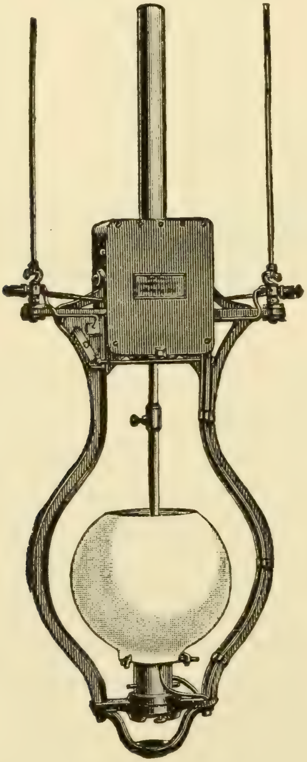

Fig. 215.

fed downward by mechanism contained in the box above, and is carried by a vertical round rod called the carbon holding rod.

The regulating box contains mechanism for feeding the carbon as fast as it is consumed, and at the same time to maintain the arc or space between the carbons in burning, of such extent as to give a steady light.

The lamp contains an automatic safety device for preserving the continuity of the circuit in case of accidental injury to the feeding mechanism or the carbons of the lamps.

THE MÜLLER ARC LAMP.

The arc lamp invented by Mr. Müller, fig. 216, has a novel air check, which regulates the movement of the upper carbon. The lamp is made in two forms, one burning a simple pair of carbons and limited as to the time it will burn continuously; the other form is of the same general construction, but made in duplicate, so that it will burn two or more pairs of carbons in succession.

In this lamp, when the light-arc is very small, there is very little resistance in the circuit, and the helix draws its core inward, raising the free end of the lever, A, as far as the upper screw will permit. This causes a pawl to engage with the ratchet-wheel of the feeding mechanism, which is rotated a short distance in the proper direction to raise the positive-carbon holder and lower the negative-carbon holder, thus separating the carbon points. This operation is repeated every time the carbons approach each other too much. The rapid descent of the carbons is prevented by the piston attached to the upper or positive-carbon holder. The weight of the upper carbon and its holder, acting on the ratchet-wheel and its shaft, raises the lower carbon holder. As the positive carbon is consumed twice as rapidly as the negative carbon, the wheel which it moves must have twice the diameter of the wheel which moves the negative carbon. As long as there are any carbons in the first lamp, the current passes into the positive-carbon holder, the positive and negative carbons, the helix, the joint piece of the armature, and from there to the generator. During this time, the armature at the side of the helix is attracted by the pole piece at the lower end of the helix. As soon as the first set of carbons is consumed to such an extent as to interrupt the circuit, the side armature is released from the pole piece and is pressed against a contact-strip which sends the current through the second set of carbons. As soon as the second set of carbons is consumed, the armature of that lamp is released in the same way, sending the current to the third set and so on.

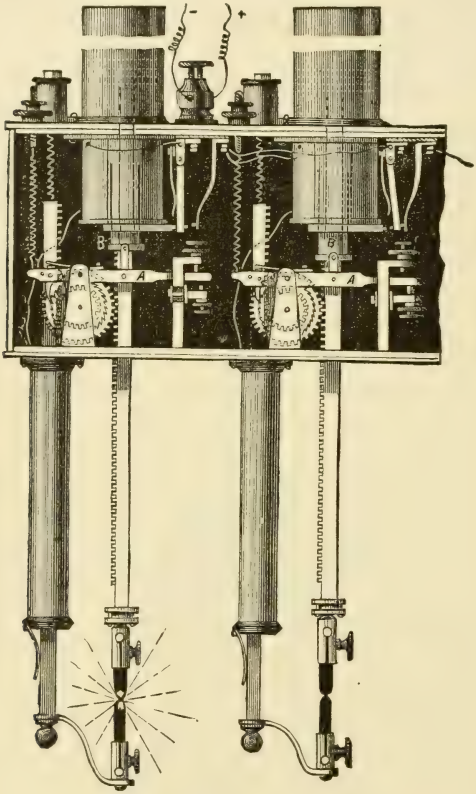

Fig. 216.

THE SERRIN ARC LAMP.

Fig. 217 represents the Serrin regulator. At the top of the lamp is a horizontal connecting link, which may be moved to

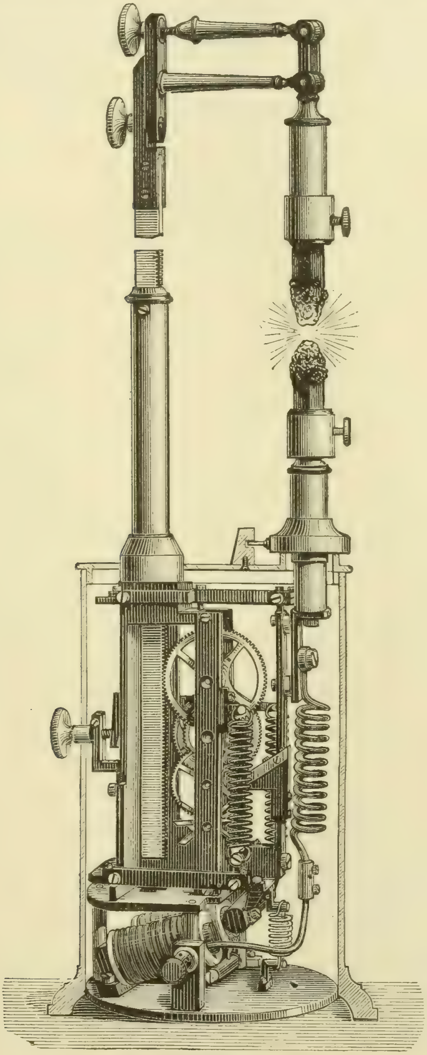

Fig. 217.

and fro by means of an adjusting screw. The stud immediately below is attached to a small eccentric, and by turning the two the upper carbon holder can be moved in both directions, so as to adjust its point exactly opposite to that of the lower carbon. The vertical rod holding the upper carbon slides in the vertical standard and extends into the body of the lamp, the lower part being provided with a rack. It is this rod which, by its gravity, forms the motive power of the lamp.

The rack-work of the positive carbon holder acts on a series of multiplying wheels for the increase of speed, the last of which corresponds with a wheel carrying a certain number of long teeth in the form of a star. When no current passes, and the carbons are separated, a motion of the wheels takes place until the carbons touch. At that moment the electro-magnet becomes active, attracts its armature, and causes the descent of a movable oblong check to which it is fixed; this catches the toothed wheel, stops the descent of the upper positive carbon, and lowers the negative carbon, which is fixed to this movable piece. If the arc is lengthened, the strength of the current is lessened, the movable piece ascends under the action of two supporting springs and liberates the large toothed wheel. The upper carbon can now descend a certain distance, until the arc is sufficiently shortened and the strength of the current restored to its normal condition, when a fresh stoppage ensues, and thereby establishes a new state of equilibrium. If, on the contrary, the carbons are too close to one another, the strength of the current increases, the movable piece is more strongly attracted by the electro-magnet, and continues to descend, producing a lengthening of the voltaic arc. On the left of the figure is a screw which tightens or loosens the retractile spring of the electro magnet. In this form of the Serrin lamp, constructed by Suisse, the luminous point changes and descends in proportion to the consumption of the carbon. In an improved model, the luminous point remains constant, because the positive carbon descends and the negative carbon ascends at the same time at a relative rate previously calculated, and which is nearly as two to one.

THE SCHMIDT ARC LAMP.

Among the arc lamps shown at the recent International Exhibition of Electricity, at Munich, was a full series of Mr. Franz Schmidt's regulators. The principle upon which these apparatus are based is explained by the diagram in fig. 218. Each of the electros, A, B, C and D, is doubly wound with coarse and fine wire. The coarse wire of the four electros form, with the arc, the principal circuit, and the direction of the winding is such that, when the current passes, B and D, as well as A and C, tend to recede from each other. The fine wire, in derivation on the arc, forms a circuit wound in such a way that, under the influence of the current that is traversing it, B and D, as well as A and C, tend, on the contrary, to approach one another. When the lamp is in operation, these two actions counterbalance each other so as to keep the carbons at a normal distance apart. When the arc becomes too large, the juxtapositing current increases and the carbons are brought back to their first position.

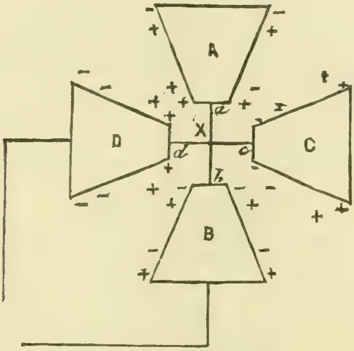

Fig. 218.

Figs. 220 and 223 show two applications of this principle with four and two electros. In the apparatus in fig. 221 the two electros, B B′, that attract and repel each other, are mounted on rails, R, and guided by a rod, T. In the arc in fig. 222, the motions of the electros are transmitted to the carbons by a double sys-

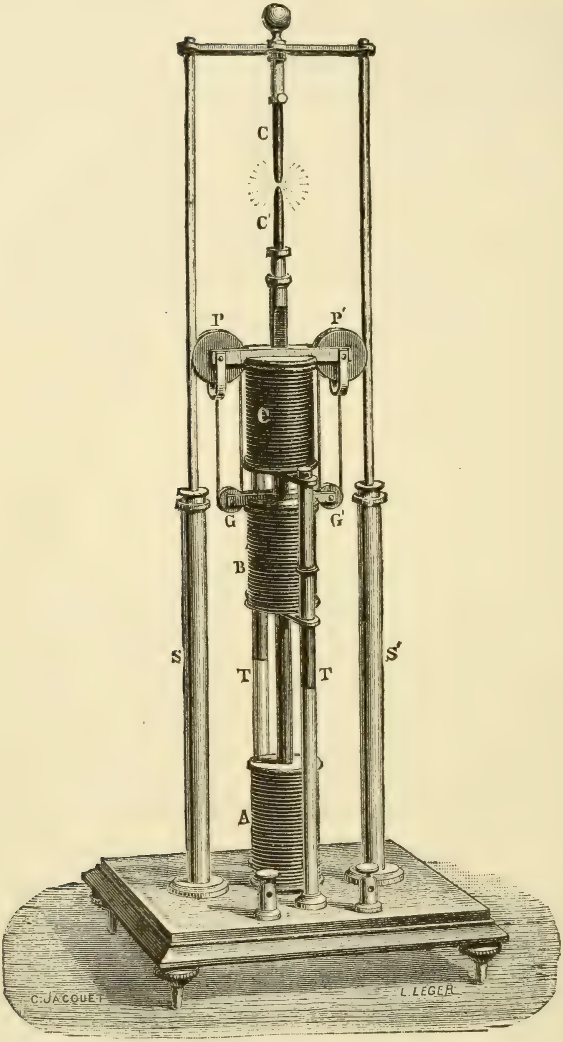

Fig. 219.

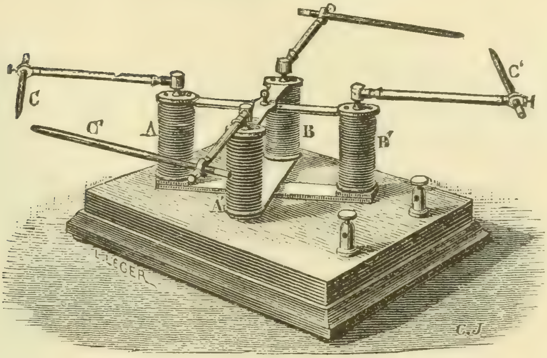

Fig. 220.

tem of racks. Finally, in the lamp shown in fig. 219 the action exerted between A and B is combined with that which takes place between B and C. All these apparatus are evidently ingenious, but they possess no practical value.

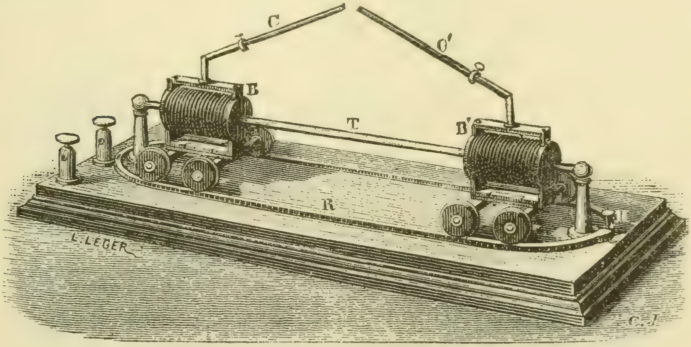

Fig. 221.

THE RÉGNARD ARC LAMP.

This regulator has screw-shaped carbons, which move forward or backward by the action of two female screws, which are set in motion by a spring controlled by an electro-magnet, similar in principle to that employed by Duboscq, described on page 8.

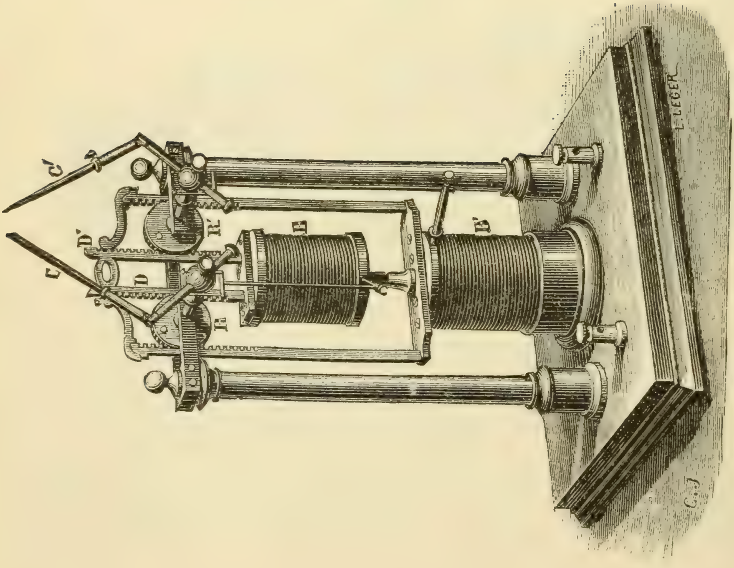

Fig. 222.

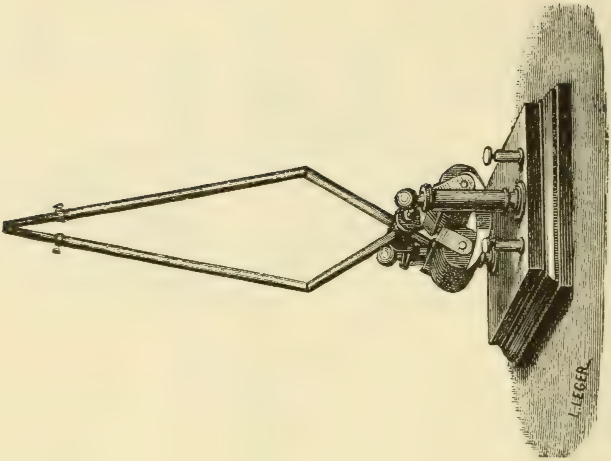

Fig. 223.

THE COLBURN ARC LAMP.

Fig. 224 is a general view of the Colburn lamp. The positive carbon is fed downward by gravity, and controlled by an electro-magnet. The action of the lamp is very simple. When a current passes through the lamp it magnetizes an electro-magnet and draws down an armature. This action tightens a clutch on the positive carbon holder rod, and separates the carbon about $\frac{1}{32}$ of an inch. When the carbons are consumed so that the arc is about $\frac{1}{16}$ of an inch in length, the re-

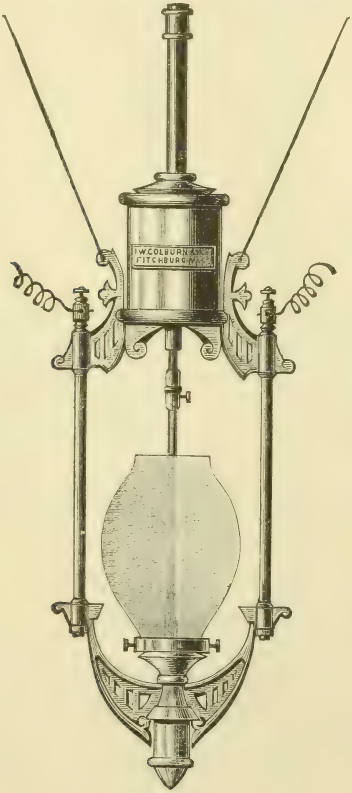
I.W.COLBURN & CO.
FITCHBURG MASS.

Fig. 224.

sistance of the arc becomes so great that enough current passes through an electro-magnet shunt to loosen the clutch, which allows the carbons to approach until they are again $\frac{1}{32}$ of an inch apart. This action goes on until the carbons are consumed. There is a glycerine dash pot which regulates the action of the clutch on the brass rod carbon holder, thus preventing any sudden action, and also enables the carbons to approach each other until they are entirely consumed, and never to come in contact while the current is flowing through the lamp. There is a resistance coil through which the current is shunted if the mechanism in the lamp ever fails to work, or if the carbons are entirely consumed, the current is switched through this coil. This coil is of the same resistance as the arc, so that if the lamp for any reason ever goes out, the other lamps in the same circuit are not affected.

The front part of the cylindrical case can be easily removed if necessary, to get at the mechanism of the lamp. It is not necessary to remove the glass globe to place the carbons in position. The negative carbon is inserted through the bottom of the lamp by removing the conical shaped terminal, and the positive carbon is placed in position without removing anything.

The lamp is finished in bronze and nickel, and is very ornamental.

THE DORNFIELD LAMP.

Fig. 225 represents the Dornfield lamp. The two carbon holders, *a* and *b*, are suspended by cords passing over two pulleys fixed to the same shaft. The pulley over which the cord of the positive carbon, *a*, passes, is twice as large as the pulley to which the cord of the negative carbon, *b*, is attached. By this arrangement the uneven wear of the two carbons is compensated, and the focus of the light is kept stationary until the carbons are consumed. To regulate the fall of the upper carbon holder, *a*, which must not be made very light, lest its travel should be checked by dust or oil, a fly, fixed to a shaft, carries a small pinion gearing into the toothed wheel on the horizontal

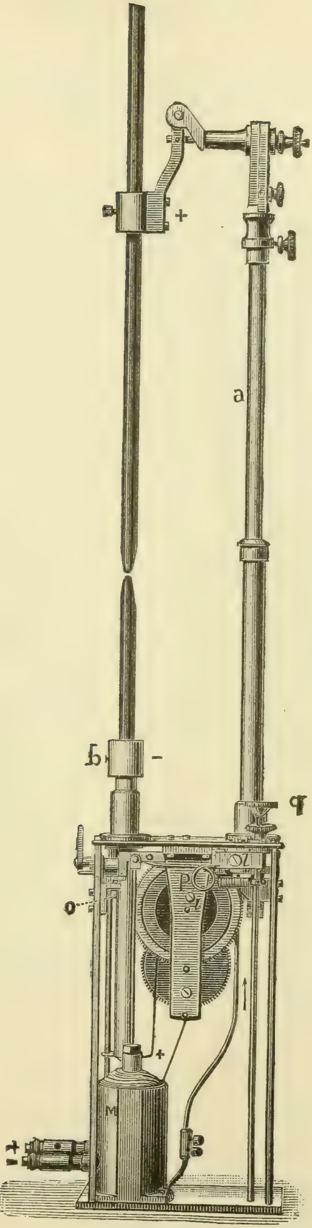

Fig. 225.

shaft. By this arrangement the resistance of the air is employed to regulate the speed with which the rod, *a*, is allowed to run down.

The toothed wheel is not keyed to the horizontal shaft, but connected to it by a ratchet clutch, so that when lifting the holder to insert a new carbon, it can be raised without rotating the wheel train.

The distance between the two carbon points is regulated by a friction brake, acted upon by a solenoid, the coil of which is constantly in circuit. On the same shaft that carries the cord pulleys is fixed a friction disk, acted upon by a brake, which is moved by the solenoid plunger, M. When the circuit in the lamp is closed, while the two carbon points rest upon each other, the solenoid plunger, M, is attracted, and by means of a brake actuates the friction disk, thus separating the two points to the desired distance, which can be adjusted by the set screw, O. As the carbons burn away, the current in the solenoid becomes weak, and the magnetic attraction is overcome by a spiral spring, *p*, the strength of which can be regulated by a set screw, *q;* the carbon points then move toward each other till the strength of the current is sufficiently increased for the solenoid to recommence its action.

THE CLERC LAMP.

Figure 226 represents one of the earlier forms of the incandescent arc lamps, invented by M. Clerc, known as the Lampe-Soleil.

Two carbons, inclined at an angle of 40°, slide, impelled by their own weight, in a rectangular block formed by the combination of refractory materials. The arc playing between the extremities of the carbons, heats internally the vertex of an angular piece of marble placed on the bottom or side of the block, and the luminous rays are projected in a very open conical sheaf, either downward, as shown in fig. 226, or sideways, when the open part of the piece of marble is placed on the side of the block.

For lighting, the extremities of the carbons are connected by a wick impregnated with a paste of carbon. This conducting wick allows, first, of the passage of the current, then it is destroyed and the arc is formed. The light is produced as much by the arc itself as by the incandescence of the marble, which is transformed into lime by the heat of the arc.

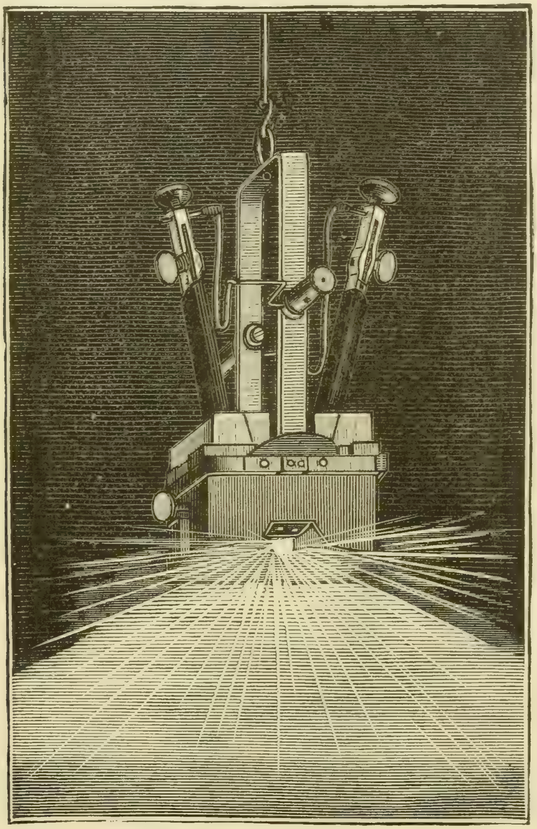

Fig. 226.

The diagram, figure 227, shows the connections for working the lamp. A wire from the machine goes to the single block of the switch, and above this two wires are led to the globe, one for each lamp, L, L, a common return being used through a hollow coil, *s*. By plugging up either the right or left hand hole in the switch, the current may be sent either into one or the other of the two lamps. We have for simplicity only shown one double lamp in the circuit, although there arc actually two.

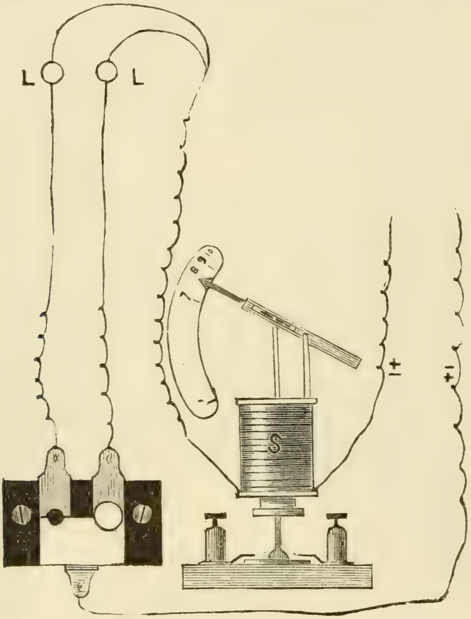

Fig. 227.

A core in the hollow coil moves an index arm over a scale graduated in ampères arrived at by comparison with a Siemens electro-dynamometer. Should any accident happen to the circuit, this core would drop upon and short circuit the two springs underneath, which are attached to the two small terminals between which a battery and bell may be placed so as to give an alarm.

Figure 228 shows an ingenious and simple form of self lighting lampe-soleil.

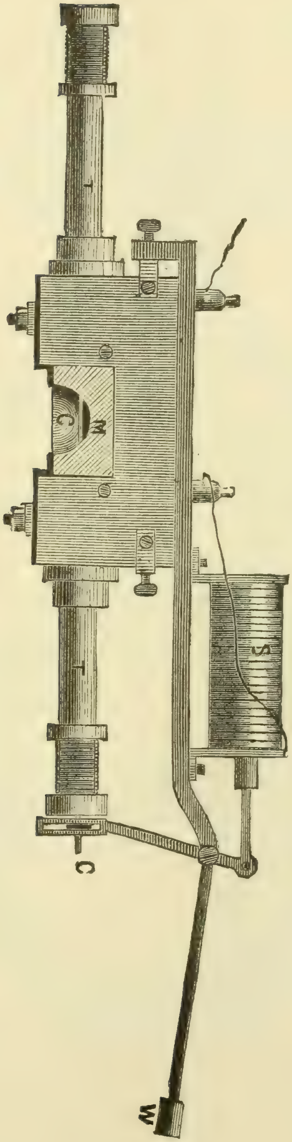

Fig. 228.

As the carbons consume they are pushed forward by the loosening of the spiral springs encircling the tubes, the movable shoulders to which one end of the respective springs are attached being allowed to slide in a groove cut in the sides of the tubes. The ends of the carbons rest on each side of the cavity cut in the marble block, M. One of these carbons is hollow, and passing through it is a small carbon pencil, C, which reaches across the chamber in the marble and touches the other carbon. On the top of the lamp is a solenoid, S, whose core in its normal state is pulled nearly out by the weight W, at the end of a pivoted lever. When a current passes through the apparatus the core is drawn inside the solenoid and the lever lifted, which in its turn draws out to a certain distance the carbon pencil, C. Of course directly the small carbon breaks away from the end of the large one an arc is formed, which follows the withdrawal of the pencil until it reaches the end of the large hollow carbon. The lamp then continues burning, the carbons being pushed forward as consumed.

Figure 229 is a general view, and figure 230 shows the mechanism of M. Clerc's latest improved form of the lampe-soleil. The carbon rods, one of which is solid and the other drilled—for the purpose of allowing a small carbon rod to be passed through, which makes contact with the end of the solid carbon, and which being withdrawn, either by hand or automatically, forms the arc between the two carbon rods—are placed horizontally, and as they consume they are gradually pressed forward by means of springs (easily traced in the figure) which short-circuit the lamp when the carbons have been pushed to their distance limit. A safety switch is mounted on the upper portion of the lamp bracket, through which the current passes by two paths.

A portion goes through the German silver resistance coils, shown on each side, then through two mercury cups connected together by means of a metal fork attached to a soft iron core, and from thence to line; the other part traverses the main circuit, consisting of a short coil of moderately thick copper wire,

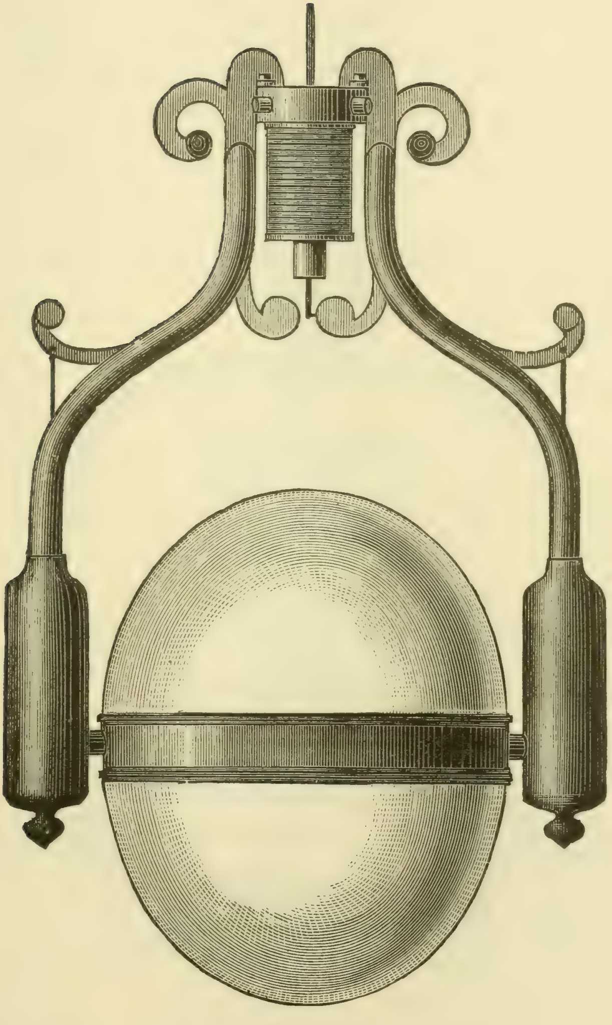

Fig. 229.

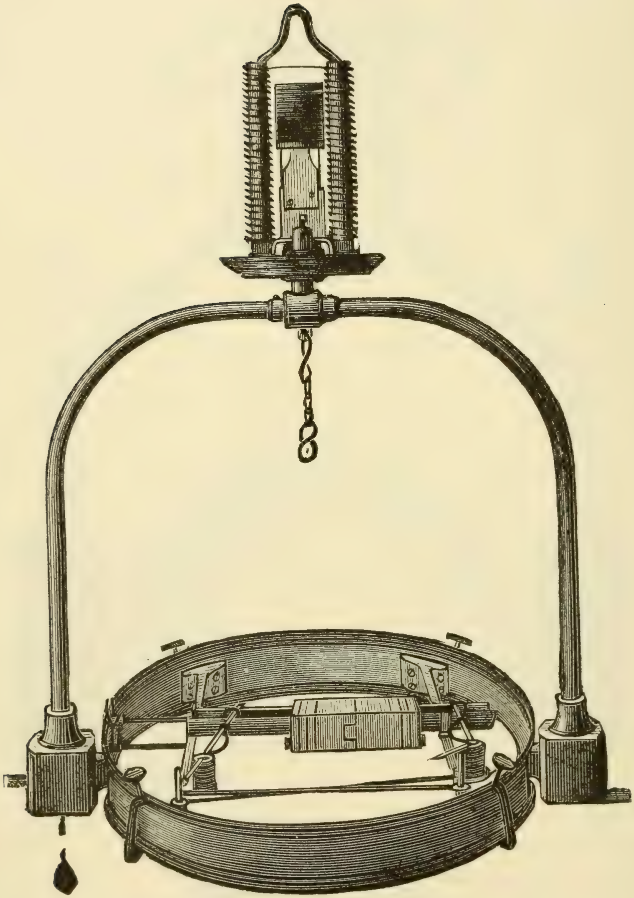

Fig. 230.

then the drilled carbon rod, across the connecting projection of the small carbon pencil to the other carbon and to line. The effect is that the soft iron core is pulled into the main circuit coil, and the metal fork being lifted out of the mercury cups the derived circuit is broken. Should any accident occur to the working parts of the lamp, such as an extinction and being unable to relight, the core drops again, the circuit is completed, and the remainder of the lamps on the same line are unaffected. The main circuit coil is shown in detail in figure 231, together with the mercury cups.

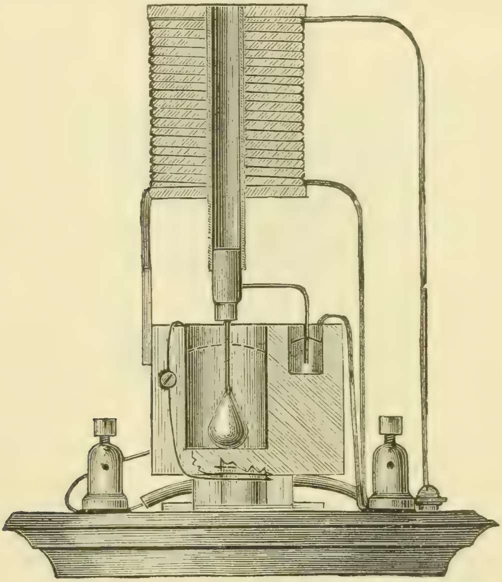

Fig. 231.

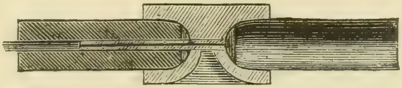

Fig. 232.

Figure 232 is a sketch of the carbon rods and the carbon pencil, which passes through the hollow one for the purpose of igniting and relighting.

THE SOMZEE LAMP.

Figure 233 represents an electric regulator invented by Mr. Somzee, in which the sloping tubes cause finely powdered carbon to fall into the electric arc, in order to increase the quantity of solid particles raised to incandescence.

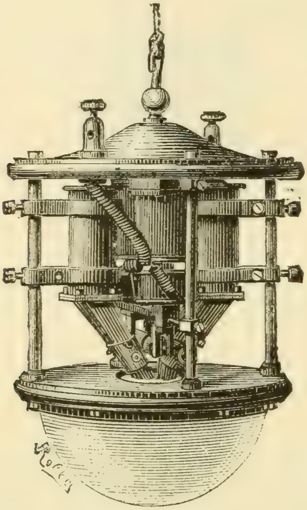

Fig. 233.

THE LONTIN LAMP.

None of the earlier forms of arc regulators allow of more than one lamp being placed in the same circuit, for the reason that the movement of the carbons is effected by an electro-magnet which is governed by the variations in the strength of the currents produced by the lengthening or shortening of the arc. If two lamps are placed in the same circuit, the lengthening of one of the two arcs is sufficient to set the two electro magnets in action, and at the same time to shorten both the voltaic arcs; upon this the second lamp immediately ceases to act, when it is merely a question of regulating the distance between the carbons of the first. In other cases one arc might be very long and the other very short without interfering with the equilibrium, since the strength of the current would be the same as if the two arcs had the mean length necessary for their efficient working. The connection of the two regulators, therefore, entails in each of them changes which finally result in a complete disarrangement of the whole apparatus.

Within the last few years, however, a number of regulators have been constructed which permit of many lamps being successfully used in the same circuit without interfering with each other. All the regulators employed for this purpose are founded on the principle of derived or shunted currents. The priority for the application of the principle of shunts to electric arc regulators has been claimed by Lontin, Tchikoleff, and Von Hefner Alteneck.

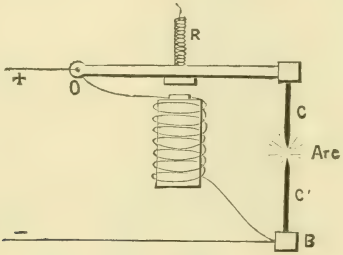

Fig. 234.

M. Lontin's electric arc regulator (fig. 234) is based on the laws of derived currents which may be expressed simply as follows: When from any electric source there issue two circuits with different resistances, in each of them there passes a current whose strength is in inverse proportion to the resistance. If we compare the source of electricity to a reservoir of water placed at a certain elevation and the circuits of unequal resistance to two delivery pipes of unequal diameter, we know that the larger pipe will allow of the greater outflow of water; and just so the less resistant circuit will allow the greater quantity of electricity to pass. Starting from this principle, it is easy to understand the mechanism of M. Lontin's regulator. The current from the positive pole of the generator comes to the lamp, at *o*, (fig. 234,) where it divides, a portion passing over the horizontal rod to the upper carbon *c*, thence through the arc to the lower carbon *c*′, thence via B to the negative pole of the generator. The other portion of the current which divides at *o*, passes through the coils of a fine wire electro-magnet of great resistance to B and thence to the generator. The armature of this electro-magnet, when it is inactive, arrests the mechanism which serves to approximate the carbons. The apparatus being properly regulated, the greater part of the current passes into the voltaic arc, because its resistance is infinitely weaker than that of the electro-magnet. But upon the wasting away of the carbons, the resistance of the voltaic arc increases with their distance, and the result is that the strength of the current which traverses the electro-magnet increases until it is sufficient to cause the latter to attract its armature (which is sustained by a spring R, regulated beforehand), and to set free the mechanism that draws the carbons toward each other. In proportion as such approximation takes place, the resistance of the arc diminishes, and the electro-magnet becomes weaker and drops its armature; and then the latter arrests the forward movement of the carbons, and so on.

VON HEFNER ALTENECK'S DIFFERENTIAL REGULATOR.

Von Hefner Alteneck's differential arc lamp, constructed by Siemens, is shown in Fig. 235. The regulator depends for its action upon the principle of shunted currents, and of the differential force which they exert in proportion to their relative strengths. The current, arriving from the machine at L, fig. 236, is divided into two parts; one part of the current traverses a coil, T, formed of very fine wire, and of great resistance, and leaves by *b* L′ to enter the following lamp; a second part of the current traverses a coil, R, with a coarse and short wire. On leaving R, it traverses the lever *d c*′ *a* and the arc formed between the carbons, *g*, *h*, and passes from *b* L′ over into the following lamp.

The current is thus divided into two very unequal parts; the weaker traverses the coil, T, which has a fixed and large resistance. The greater part of the current traverses the voltaic arc, which constitutes a variable resistance with the withdrawal of the carbons. In the interior of each coil there is a soft iron rod, *s s′*, connected by a lever, *c d a*, with the carbon, *g*. Each of the coils attracts its corresponding solenoid with a force proportionate to the strength of the current traversing them. It is

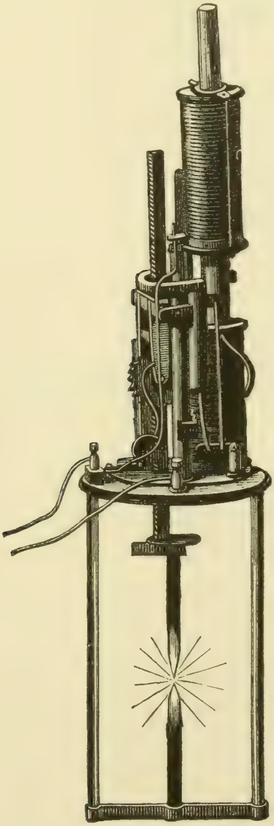

Fig. 235.

clear, therefore, that for a convenient resistance of the voltaic arc, the relative resistances of the two circuits will tend to equalize the actions of the coils on the rods, *s s*, and the lever, *c d a*, will take up a certain position of equilibrium. If the resistance of the arc increases, this equilibrium will be destroyed, the action of the coil, T, will become predominant, the lever, *c d a*, will oscillate round *d*, and will cause an approach of the carbons. The opposite effect will be produced if the resistance diminishes, for then the coil, R, will act more energetically on the rod *s*, and a withdrawal of the carbons will ensue. The regulator no longer acts by the variations of the strength of the current in the circuit, as in Serrin's lamp, but by the variations of resistance of the arc. If the action of the coil, T, preponderates, a small ratchet wheel is released, which allows the upper carbon to descend by its own weight. In order to render that descent slow and regular, there is a sort of small pendulum, which only allows the escapement of one single tooth by oscillation, and as the descent can be arrested at each fifth part of an oscillation of the pendulum, the movements are absolutely imperceptible, and do not interfere in the slightest degree with the steadiness of the light.

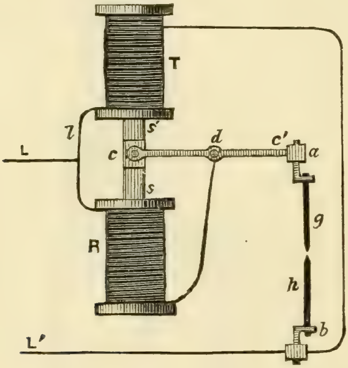

Fig. 236.

The solenoid is connected with a little air pump, in order to render its movements more gentle, and to prevent it from vibrating under the influence of the alternate current. When the withdrawal of the carbons is produced, the mechanism is raised, together with the upper carbon, until the distance is reached for which the apparatus has been regulated. This regulation is very easily effected, without a spring, by raising more or less the coil of fine wire, in order to vary its action. The lower carbon being fixed, the luminous point descends in proportion to the consumption of the carbons, but as the mechanism is placed altogether above the luminous point, no shade is thrown by the socket of the apparatus, and this displacement entails no inconvenience under these conditions, especially when the lamp is placed rather high. The mechanism is hidden in a copper cylinder, which preserves it and is used for its suspension. The rack-work of the movable carbon-holder carries a small cross-beam; when the rack-work is at the end of its course, this cross-beam presses against two small platinum contacts connected with the terminals, and establishes a direct communication. This prevents the extinction of all the lamps of one circuit when the carbons of one of these lamps are used up, and it has been forgotten to replace them in time. A generator with sixteen bobbins expends with its charging machine about ten horse power, and feeds twenty lamps of a power of about twenty-five carcel burners each. Ten of these lamps can be successfully placed in series on the circuit of a Siemens alternating current machine, each lamp being independent in its action of all the others.

THE TCHIKOLEFF LAMP.

The Tchikoleff regulator, fig. 237, is based upon the differential action of derived currents. E E′ are electro-magnets, to the poles of which are attached circular plates of iron *a*, *b*, which nearly envelop an armature K, composed of a ring of soft iron, with insulated copper wire wound over its surface. The rotation of the armature causes the carbons to move by the action of a right and left screw on the two nuts B, C, which serve as carbon-holders. The screw D is used to raise or lower the luminous point. The current passes from the positive pole of the generator to the negative pole by three derivations or branches, one of which, after having traversed the arc, reaches the ring by the brushes *m*, *n* ; a second, which after having also passed the arc, excites the electro-magnet E ; and finally a third, which, without passing across the arc, excites the electro-magnet of fine wire, E′, but in such a manner that its action on the spring is contrary in direction to that of E.

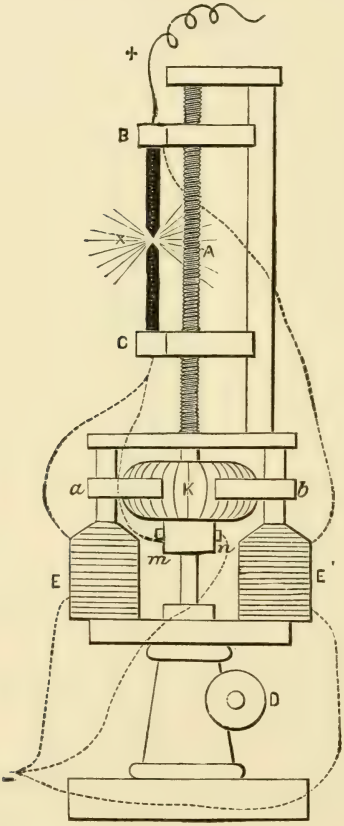

Fig. 237.

As a result of this arrangement, with a normal resistance of the arc x, the influence of the electro-magnets E, E′, on the ring K, will be about nil; but if the resistance of the arc increases, the action of the electro-magnet E, becoming more feeble, will be overpowered by that of the electro-magnet E′, and the ring K will move in such a manner as to bring the carbons nearer together. The inverse effect will naturally take place if the resistance of the arc diminish.

THE GRAMME LAMP.

The Gramme lamp depends for its action upon a derived current passing through a fine wire electro-magnet, which comes into play when the distance between the carbons increases. Fig. 238 represents a front view of the apparatus. The current is led from the generator to the terminal on top of the lamp, whence it passes by the upper carbon holder, through the carbons, thence through the rods carrying the lower holder, and, after traversing the coarse wire electro-magnets A, A, it passes back to the generator by the negative terminal which is insulated from the lamp.

The lower carbon holder consists of the slip G, carrying the carbon, the two rods, E, E, and the cross-piece C, at the top of the lamp. The cross-piece C forms the armature of the coarse wire coils, A A, which are employed for moving the lower carbon. The rods, E, E, are held up by spiral springs R R, which are attached to the rods at X and Y. These springs are sufficient to hold up the negative carbon when no current is passing; but when a current passes through the upper coils, the armature C is attracted and forces the lower carbon down to the extent of its motion, which is very slight, the feed being almost wholly confined to the upper carbon. The electro-magnet B, coiled with fine wire, is the main agent in this operation. On the top of this magnet rests a platform having two small standards, K. These carry by screw trunnions, V, the balanced lever L, which is normally maintained in a horizontal position by the coiled spring, U. This spring can be delicately adjusted to set

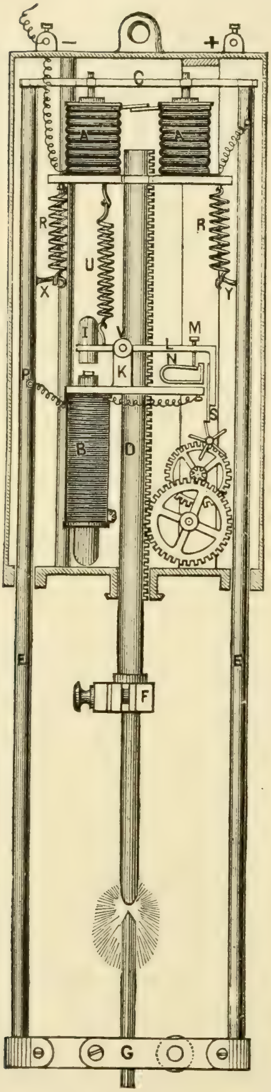

Fig. 238

the lever, L, in its right position. At one end of this lever is the armature, I, at the other end of the lever, L, is the adjustable screw, M, which presses upon the bent spring, N, fastened to the frame on the top of the electro-magnet, B. From the lever L depends an arm carrying the spring, S. This spring engages in the star wheel below, which is the last of the train of clockwork, the first wheel of which gears in the rack on the side of the positive carbon holder, D. The derived current to the electro magnet, B, is taken by a connection from the positive pole to the insulated spring, N, whence it passes, when the arc is of normal length, through the lever L and its trunnions, V, to the coils, which are coupled at their other extremity to one of the negative rods at P. The upper carbon holder, D, is tubular, and is guided by a socket in the bottom plate of the case.

The action of the lamp is as follows: So long as the principal current maintains a certain strength, that is to say, as long as the arc is not of too great a length, the spring, S, holds the star wheel and prevents the positive carbon from descending by its own gravity; but as soon as the arc lengthens, and the resistance is increased, the electro-magnet, B, comes into action, and attracts the armature, I, the movement of which draws down the lever, L, on which it is mounted, and lifts the spring, S, clear of the star wheel, thus releasing the clock work, and allowing the positive carbon holder to fall by its own weight, and thus to bring the carbons closer together. At the same time, the contact between the spring, N, and the stud, M, is broken by the tipping of the lever, L, and the current ceases to pass through the magnet, B. The armature, I, drawn up by the spring, U, regains its horizontal position, and the regulator resumes its action; but if the arc be not of the normal length, the same movement recommences. It will be seen, at the moment when the upper carbon descends, the electro-magnet, A A, becomes active and attracts its armature, C, which causes the lower carbon to descend also, the electro-magnet, B, becoming, of course, inactive. This stopping of the positive and lowering of the negative carbon establishes the distance necessary to produce the arc. Five of these lamps, fed by the Gramme generator for five lights, and each giving nearly 1,500 candles, were maintained with an expenditure of six horse power.

THE DE PUYDT ARC LAMP.

Fig. 239 represents the De Puydt lamp, the arc of which is regulated by a derived current, the function of which is to maintain constant the difference of potential at the two carbon holders. The latter form racks at their upper part and are in gear with two pinions fixed upon the same arbor. These pinions are arranged for keeping a fixed luminous point, in contrast to the action of most lamps where the arc descends according to the consumption of the lower carbon. Upon this arbor is also fixed the first of a series of gear wheels, A, put in motion by the weight of the upper carbon-holder. The last wheel of this oblique escapement bears projections which are engaged or disengaged at the proper time by a stop *a*, fixed to the armature of the fine wire electro-magnet, Q, which is traversed by the derived current. Another electro-magnet, P, is actuated by the current of the arc and in attracting its armature, P^1, makes the whole clockwork movement oscillate around the lower arbor, upon which are fixed the pinions working the racks. There are in this apparatus two distinct actions: First, the attraction of the thick wire electro-magnet, P, which produces at the outset the separation of the carbons by making the clockwork movement describe a certain angle, which communicates motion to the two pinions which govern the carbon-holders; second, the attraction of the fine wire electro-magnet, Q, which keeps this distance fixed by disengaging the gear wheels directly the difference of potential has exceeded the proper limit. An important detail to be observed is that the armature, Q, as well as the stop are supported by the arbor of the origin of motion, so that in turning slowly on disengagement, this arbor immediately returns the stop to the position of engagement. In this way the carbons only travel an imperceptible distance at a time and at very short intervals.

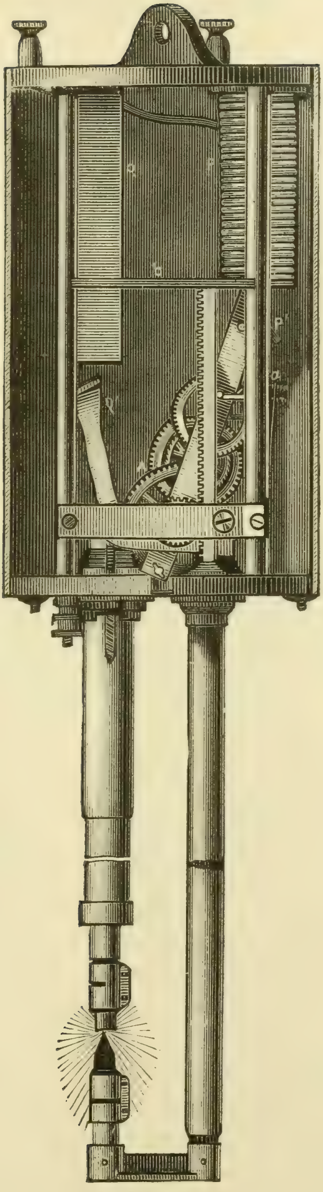

Fig. 239.

A screw serves to regulate the distance at lighting, and another screw, which stretches more or less the counterspring of the armature, Q^1, serves to keep this arc at the desired length.

In the first case, the cover of the regulator being raised, raises the upper carbon-holder; then, while it descends with its rod, the height of the screw is regulated, forming a stop at an angle from the armature, Q^1, so that there exists between the internal surface of the electro-magnet, P, and of the end of the armature, P^1, a distance of half an inch for the Gramme 5-light machine, and of three quarters of an inch for that of the workshop type.

In the second case, the distance of the carbons is regulated during the working of the lamp. This distance ought to be for the two machines mentioned one tenth and one sixth of an inch respectively.

At the time of regulating, when the distance is too great, the nut on the screw, to which is attached the spring of the armature, Q^1, is loosened, in order to slightly relieve the latter; on the contrary, if the distance is too small, this spring is tightened until the steadiness of the arc be obtained.

THE GERARD ARC LAMP.

Fig. 240 represents the Gerard lamp, in which the regulator is placed above the carbon, and is worked by alternating currents. It consists of a hollow electro-magnet allowing a free passage for the upper carbon. The electro-magnet is made of fine wire and is mounted in a shunt on the terminals of the lamp. An articulated brake, with a screw, keeps the upper carbon in position; the pressure of the brake against the carbon being regulated by a spring. The upper part of the brake carries an armature, and when this armature is attached, the brake frees the carbon and allows it to descend.

The lower carbon is supported by a movable vertical frame carrying an armature at its upper end, and this armature is placed at the lower extremity of the electro-magnet. The movable frame is balanced by two spiral springs, which are seen on the right and left of the electro-magnet. When they are at rest the carbons are not in contact. The apparatus is worked in this way: When the current passes into the lamp, the carbons are separated, and the current, therefore, can only pass through the fine wire. The electro-magnet, consequently, becomes strongly charged, and attracts both the upper and lower armatures. The upper armature, acting on the brake, frees the upper carbon and allows it to descend. The lower armature raises the frame and the lower carbon. As soon as the two carbons are in contact, the arc is formed, and the current which passes into the shunt is sensibly weakened. The lower armature is released, and causes the lower carbon to descend, and thus produces the requisite distance between the two carbons. At the same time the lower

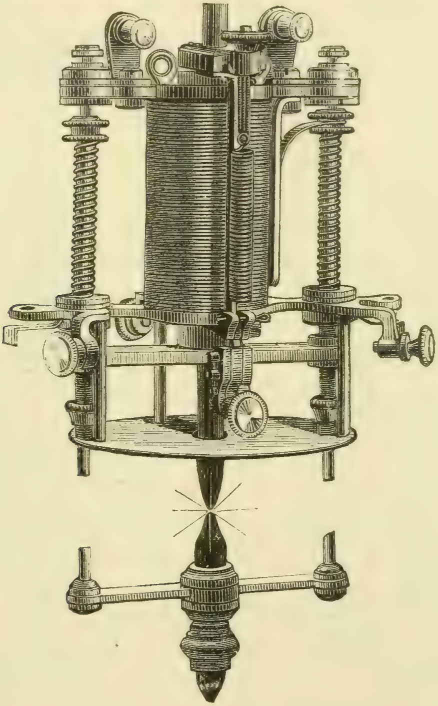

Fig. 240.

armature of the brake is partly released, and the screw presses against the upper carbon and prevents it from descending.

If the spring is properly adjusted, a balance is established; but in proportion as the carbons are consumed, the arc will be lengthened, and the strength of the current in the electro-magnet will increase. The brake is now gradually loosened, the alternating current will produce an oscillation of the armature, and the upper carbon slides down imperceptibly and continuously to maintain the requisite distance.

THE BRUSH ARC LAMP.

The electric lamps designed by Mr. Brush are among the simplest in construction of all arc regulators, involving no clockwork or complicated feeding mechanism, or anything that is liable to become deranged. They can be constructed to burn continuously for eight, sixteen or twenty-four hours, and the mere hanging of a lamp in its place puts it into the circuit of the other lamps of the series; while the extinction of one or more lamps, or their removal altogether, does not affect the others. The great simplicity of the Brush lamp consists in the fact that the feed is actuated by gravity alone, while it is controlled solely by the influence upon a bar of iron of a magnetic field, the intensity of which varies with the strength of the electric current passing through the lamp circuit. The general external appearance of six forms of Brush regulators is shown in figs. 241 to 246, the first representing the single carbon or eight-hour lamp; the second the double carbon, or sixteen-hour lamp; the third is a double carbon lamp with a post socket; the fourth is a sketch of a more ornate form of the double carbon lamp, the controlling apparatus being enclosed in a nickel plated case; the fifth is a street lamp; and the sixth is an insulated lamp in which the light is enclosed in a glass globe, with a close fitting bottom plate, a spark arrester above, and the carbon rod and regulating apparatus likewise enclosed in metallic cases, all of which, as well as the outer frame, are insulated from the circuit. Fig. 247 shows how the lamps are arranged upon masts for illuminating large areas. In all these lamps, which are designed for general illumination, the lower carbons are fixed, and as they burn away the upper carbons follow them, so the arc gradually descends.

Like most of the modern electric lamps the upper carbon descends by its own weight until it touches the lower carbon, and the circuit is thereby completed; the effect of this is to cause a soft iron plunger to be drawn to a more or less extent within a hollow coil, and through the intervention of a lever and a most ingenious annular clutch surrounding the rod of the upper carbon like a washer, the upper carbon is lifted from the lower and the arc is established. As the carbons burn away the

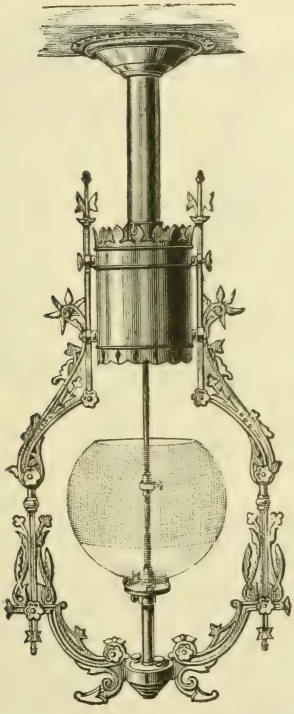

Fig. 241.

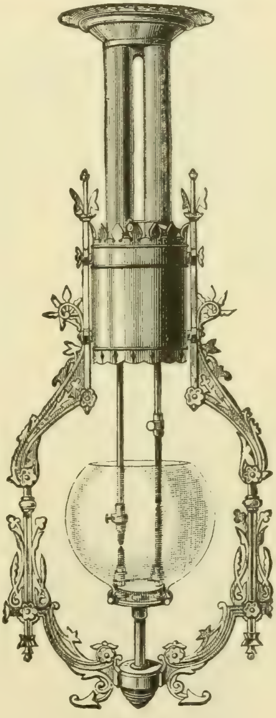

Fig. 242.

arc has a tendency to become longer and its resistance to increase, and this, by diminishing the strength of the current, diminishes the supporting power of the magnetic helix, allowing its plunger to descend, and in so doing to lower the carbon and shorten the arc until the proper strength of the current is restored, when the rising of the plunger once more holds the carbon in position.

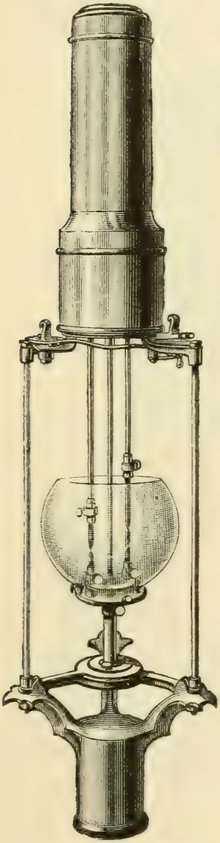

Fig. 243.

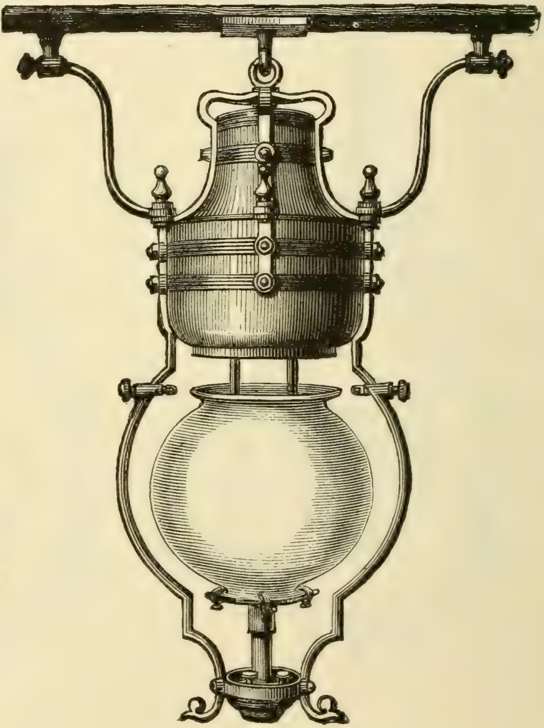

Fig. 44.

Each of the bobbins of the controlling magnet is wound with two distinct coils of wire, the first consisting of a number of turns of a thick wire, through which the current is transmitted to the arc, and the second of a much larger number of convolutions of fine wire which forms a secondary or shunt circuit between the terminals of the lamp, the connections being made in such a way that the electric current shall pass through it in a direction opposite to that in the primary or thick wire circuit, forming a shunt circuit of high resistance through the lamp,

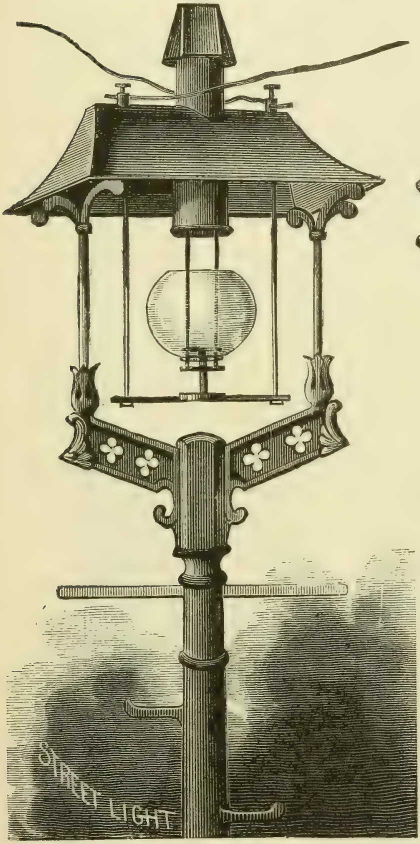

Fig. 245.

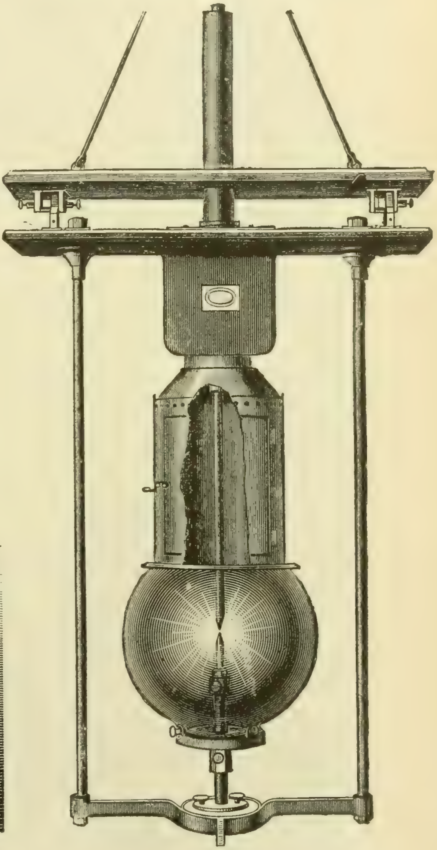

Fig. 246.

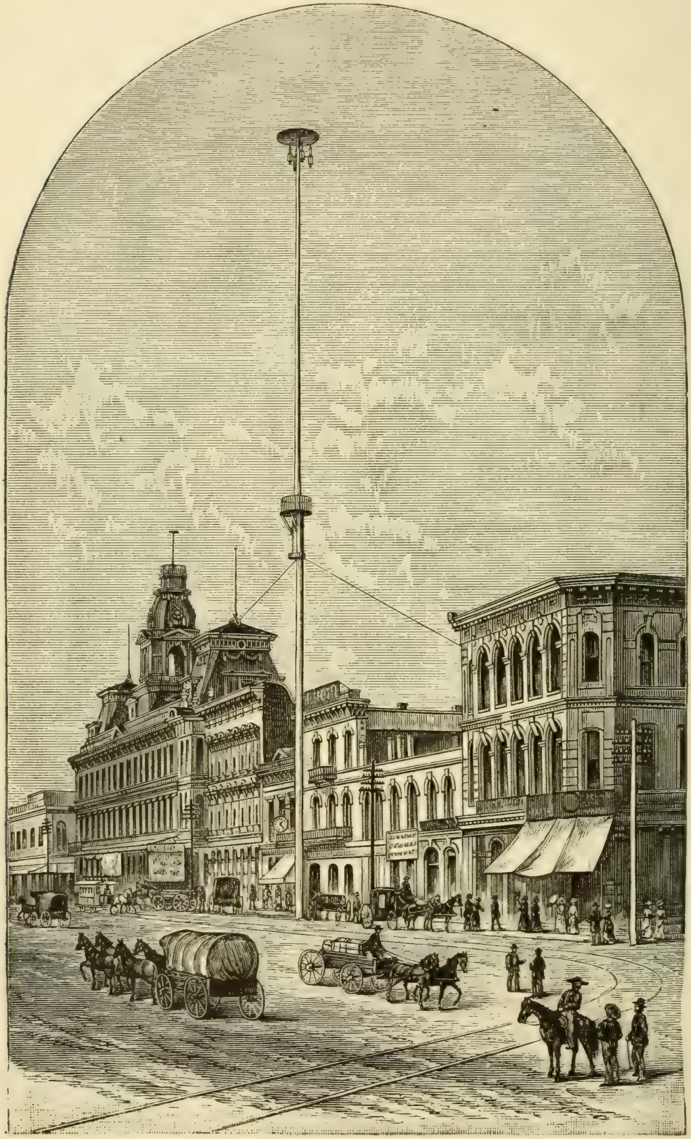

Fig. 247.

which being always closed is independent of the arc. As the current flows in opposite directions around the magnet, the influence of the fine wire circuit neutralizes or weakens the attractive influence of the thicker helix, but the number of the convolutions of the two coils, as well as their respective resistances, are so proportioned to one another that the attractive influence of the primary helix (when the arc is of its normal length), overcomes the influence of the secondary circuit. Owing to the greater resistance of the latter, not more than one per cent. of the main current is transmitted by the fine wire helix, but its magnetic influence is rendered considerable by its greater number of convolutions.

As the electric current has two routes from one terminal of the lamp to the other, the one through the arc and the other independent of it, it follows that should the arc become too long, its resistance will increase, and a larger proportion of the current will be shunted through the fine wire helix, while the strength of that in the thicker helix will diminish, the resultant magnetic influence on the plunger will be reduced, and the upper carbon will be brought closer to the lower; on the other hand, if the arc becomes shorter than its normal length its resistance is reduced, more current flows through the primary helix, and less through the secondary, and the carbons are drawn further apart.

Figure 248 is a diagrammatic sketch showing the course of the primary circuit, and illustrating the general principle by which the arc is controlled; it also shows the short circuiting contrivance by which any accident to one lamp or irregularity of working cuts it out of the general circuit, and does so without exercising any influence upon the other lamps in the series. In this diagram X and Y represent the two terminals of the lamp, which in most cases consist of hooks, which by being dropped over pins attached to the ceiling—and which are in connection with the line circuit—place the lamp in circuit with the machine. The current entering at X is transmitted through the two hollow bobbins H H^1 in parallel circuit, the outcoming ends being joined together and connected to the upper carbon-holder, N, and if the carbons are in contact the current flows through them, and by the vertical rods of the lamp to the terminal hook, Y. The effect of this is to convert the solenoids, H and H¹ into magnets, which, by drawing into themselves the two iron plungers, N and S, lifts one edge of the washer clutch, W, which, by its oblique action, seizes the carbon rod (much in the same way as a tent-rope tightener grasps its cord) and lifts the upper carbon until its influence is balanced by that of the fine wire helix, which, it must be remembered, surrounds the thicker coil.

The short-circuiting apparatus shown to the left of the carbons (figure 248), consists of an electro-magnet, T, wound with a thick and fine wire coil similar to those of the regulating solenoids, but both wound in the same direction. When the thick wire circuit of this magnet is complete, it forms a shunt of low resistance between the terminals, and, therefore, short-circuits the lamp, transmitting the current to the main circuit. Now, the fine wire wound upon this magnet is in circuit with the fine wire of the regulating solenoids; it follows, therefore, that if through a failure of the arc, or through its becoming abnormally long, or through any considerable increase in its resistance, a larger proportion of current be diverted through the fine wire circuit, the

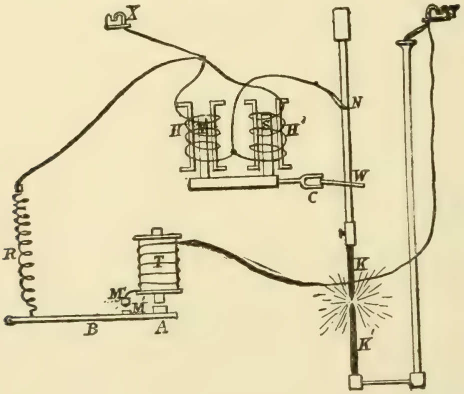

Fig. 248.

attractive force of the electro-magnet, T, would be increased, and its armature, A, which is attached to the pivoted lever, B, would be attracted, the contact pieces, M and M¹, would thereby be brought together, and the terminals would be short-circuited through the thick coil, M, and the resistance spring, R. By thus short-circuiting the terminals through a route altogether independent of either the fine or the thick wire solenoids, their magnetic action ceases, and either the upper carbon is dropped, or, if it is burnt out, or from any other cause, the arc is not established, the contact pieces, M and M¹, are held firmly together by the attraction of the magnet, T, and the current flows past the faulty lamp to the others in the series, its extinction

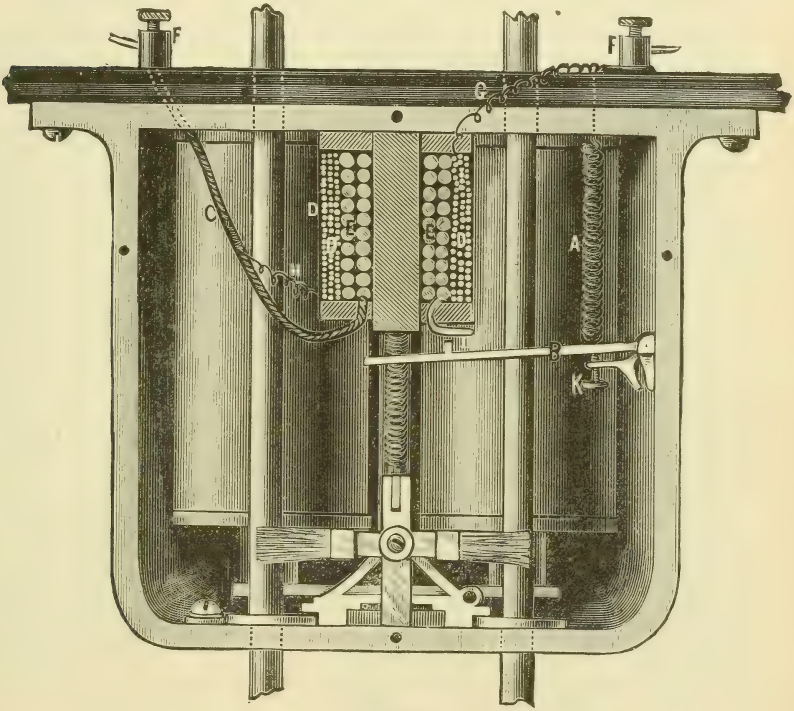

Fig. 249.

calling attention to it. Figure 249 shows the details of this automatic shunt, as constructed in a two carbon lamp.

In installations in which it is desired frequently to vary the lights burning on one circuit, and it is inconvenient to alter the speed of the machine, the automatic regulator shown in fig. 250 is employed. By this apparatus the amount of current generated by the machine is automatically controlled to suit the number of lamps in action at any one time. This apparatus depends for its action upon the fact that the resistance of a series of carbon plates varies with the degree of pressure to which they are subjected. In the arrangement shown in the figure, four sets of carbon plates, A, A, A, A, are attached to the two terminal screws, G, G^1, connected with the generator, so that the regulating apparatus forms a shunt circuit across the electro-magnet. From this it is evident that if a high resistance be placed in the shunt, the greater portion of the current generated in the machine will be transmitted to the coils of the electro-magnets, and the strength of the magnetic field will be proportionately increased; while, on the other hand, if the shunt be of low resistance, a greater portion of the current will be diverted by it from the magnet circuit, and the strength of the magnetic field will be reduced.

The columns of carbon plates, A, A, A, A, constitute the variable resistance, the pressure upon them being controlled by the lever E, actuated by the solenoids C, C^1, included in the main circuit of the machine. Thus, if any of the lamps in that circuit be extinguished, a large amount of current passing through the solenoids causes the two iron plungers to be drawn into them, the lever E is thereby lifted by the connecting rod D, and the carbon plates are pressed closer together, thus reducing the resistance of the shunt, and causing a greater amount of current to be diverted from the magnet coils. The magnetic field being thereby reduced, the machine absorbs less motive power, and when the lamps are turned on again the operation is reversed, and thus the power required to drive the generator is proportioned to the work it is required to do.

The carbon pencils consumed under the Brush system are, before being used, a foot long, and are electro-plated with a thin covering of copper; they last about eight hours, during which time about 9 in. of the positive and about 4 in. of the negative carbon are consumed. When, however, the lamps are required to burn for a longer period, double carbon lamps are employed, fitted with two pairs of carbon holders, as shown in fig. 242, and each is controlled in the same way as in the single carbon lamp,

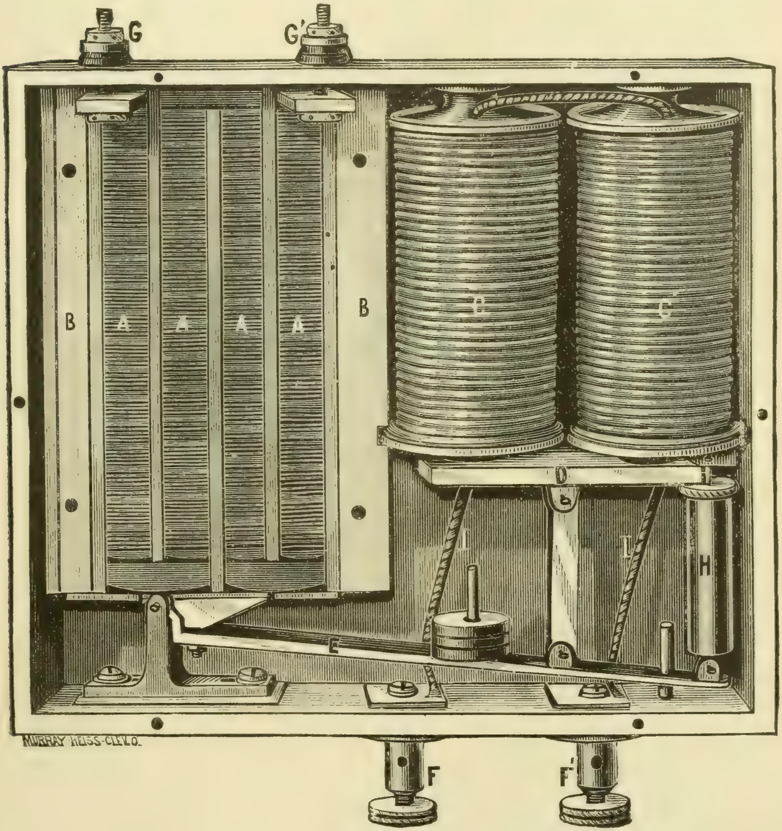

Fig. 250.

but the controlling apparatus is not duplicated. When the lamp is put into action, the arc is formed between one of the pairs of carbons, and when they have burnt out, the other pair automatically starts into action, and continues to burn until it is in turn consumed; in this way the time of burning is doubled, and in order to extend the period of burning, it is only necessary to employ a lamp with a third pair of carbons, when it will be capable of illuminating for twenty-four hours, each additional pair of carbons extending the period of burning for another eight hours

The change from one pair of carbons to another pair is effected by purely mechanical means, and by a contrivance the ingenuity of which is only measurable by its extreme simplicity. This little apparatus will be understood by reference to the explanatory diagram, figs. 251 and 252, which also more clearly illustrate the action of the washer-clutch than the preceding figure. C C is the hollow solenoid which exercises a magnetic influence upon the soft iron plunger, P. The rising or falling of this plunger raises or lowers the little frame, K (shown in both figures), by the intervention of the lever, L. R^1 and R^2 are the carbon rods which pass vertically through the casing of the lamp, and W^1 and W^2 are the clutch-washers which surround them. One side of each of these washers passes between a pair of jaws forming part of the little frame, K, and when the latter is drawn upward, its action is first to tilt the washers, and then

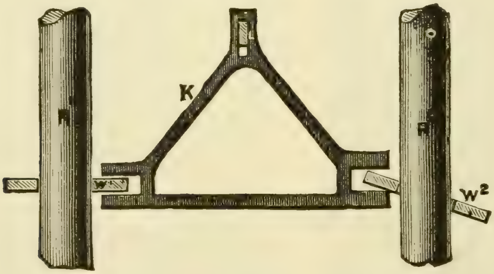

Fig. 251.

to cause them to clutch the rod on diagonally opposite corners. By the very simple device of making one pair of jaws a little higher than the other, it takes its grip before the other begins to act, and consequently lifts its corresponding carbon higher than its neighbor ; the consequence is, that only one arc is established, viz., across the lesser distance, and in all subsequent feeding and controlling, the pair of carbons first started are alone affected, because, although both carbons are raised and lowered together, the lower end of the reserve carbon is always higher than the other by the difference in the height of the two pairs of jaws on the frame, K. A time arrives, however, when, owing to the shortening of the consuming carbons, they can no longer meet when the frame is dropped, and the current by which they are again separated can only be transmitted by the reserve carbons coming into contact, the circuit is thereby completed, the new carbons are separated, and the arc between them continues to be controlled by the magnet and clutch in the same way as the first arc was.

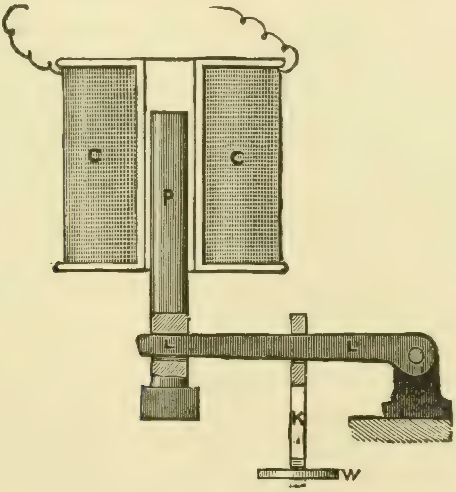

Fig. 252.

THE WRIGHT ARC LAMP.

In order to increase their duration circular carbons have been used. The first electric lamp was made by Wright on this principle. The arc was formed between carbon disks, bevelled on their circumference, and set in motion by mechanism.

THE LAMOLT ARC LAMP.

Lamolt's lamp is based upon Wright's idea, and consists of two carbon disks supported by two curved and jointed levers, set in motion by a double system of pulleys driven by clockwork mechanism. A spiral spring connecting the two curved levers, presses the two carbon disks against each other, and these are separated at very short intervals by the action of an eccentric put in motion by clockwork. The result is a series of sparks succeeding each other rapidly enough to impress the sight as a continuous light.

THE HARRISON ARC LAMP.

In the Harrison lamp one of the carbons was replaced by a carbon cylinder, movable on its axis, so as to make the consumption slower. The upper carbon was moved by an electro-magnet, which determined the formation of the arc and kept it constant. Ducretet improved this lamp by arranging it so as to give simultaneously with the arc powerful incandescent effects.

THE ANDREWS ARC LAMP.

The Andrews lamp consists of two thin plates of carbon, an eighth of an inch apart, having between them a plate of plumbago insulated by four little triangles of slate inserted between the plates. The arc is formed on the extreme edge of the plates across the plumbago.

THE FYFE ARC LAMP.

The Fyfe regulator belongs to the differential type; an ordinary clock train controlled by a shunt circuit solenoid being employed to move the carbons.

THE HUSSEY ARC LAMP.

The Hussey regulator is of the Pilsen type; its action being based upon the differential action of two solenoids.

THE BOUTEILLOUX AND LAING ARC LAMP.

In this lamp the arc is maintained by the weight of one electrode pressing upon a non-conducting core inserted in the centre of the other, and which is gradually dissipated during the consumption of the carbons.

THE BARO ARC LAMP.

Baro's apparatus is composed simply of two metallic tubes placed vertically one beside the other, and in these slide freely two sticks of carbon, which rest on a block of magnesia. These tubes are separated by an insulating substance, but a screw regulates the distance between the carbons at the end in contact with the magnesia, so that the arc may be produced at this point of contact under the desired conditions.

THE JÜRGENSEN ARC LAMP.

In the Jürgensen lamp the movements of the carbons are regulated by the differential action of two solenoids—one tending to the withdrawal and the other to the approach of the carbons—the holders of which are arranged as in Serrin's lamp, shown in figure 217, page 369.

THE CROMPTON ARC LAMP.

The Crompton regulator is a modification of the Serrin. Simple devices have been introduced in place of those of a complex character with a view to greater efficiency in working and greater economy in construction. The action of the Crompton lamp does not differ in any important particular from that of the Serrin.

THE LEVER ARC LAMP.

The Lever regulator consists of an electro-magnet wound with fine wire, whose armature lever is attached to a metal collar encircling the upper carbon holder. The current from the positive pole of the generator goes to the upper carbon holder; thence through the arc and lower carbon holder to the negative pole of the generator. The ends of the electro-magnet coils are connected with the upper and lower carbon holders, thus placing them in derivation from the arc. The action of the lamp is as follows: The carbons being separated, the only path for the current is through the electro-magnet, which, becoming charged, attracts the armature and loosens the collar attached to the upper carbon holder, which slides through its bearings by gravity. The contact of the carbons, however, allows the current to pass through them, and as the resistance is much less than through the fine wire coils of the electro-magnet, nearly all the current goes through the carbons. This causes the electro-magnet to lose its power and release the armature lever, which is pulled up by its retractile spring, and with it the carbon rod, thus forming the arc. As the carbons are burned the distance becomes greater, which increases the resistance of this route, and causes more current to pass through the electro-magnet, which, becoming stronger, again attracts the armature and lowers the carbon rod. In practice it is said that there is scarcely any perceptible motion to the lever when the arc is burning, as the electro-magnet and the spring, acting on the lever in opposite directions to each other, make a perfect balance, resulting in a steady light.

THE ABDANK ARC LAMP.

In the Abdank lamp the lower carbon is fixed. The upper carbon is movable in a vertical line, and, like the Gerard lamps, shown in figure 240, page 399, is situated below the regulating apparatus. The upper carbon holder is attached to a brass rod, which moves within the tubular core of an upright electro-magnet. The armature of the magnet has a soft iron projection on one end, which brings it much nearer the pole of the magnet than the other end, and this end being attracted first, causes the armature to assume an inclined position, which is assisted by a brass button on the opposite end from the projecting armature, which also prevents any adhesion between the armature and the core of the electro-magnet. The brass rod passes through a slot in the armature, which, when the latter is inclined by the passage of a current through the coils, acts as a clutch, and the carbon rod is lifted.

The electro-magnet is attached to a rack, which falls by its own weight combined with that of the magnet and carbon fixed to it. The length of the rack is equal to the length of the two carbons. The fall of the rack is controlled by a friction brake, which acts upon the last of a train of three wheels put in motion by the above mentioned weight, and the action of the brake is controlled by an electro-magnet whose resistance is 1,200 ohms.

The regulator, which is placed at a distance from the lamp, consists of a differential balance and cut-off. The former is composed of two solenoids with adjustable resistances. The main circuit coil is wound with thick wire, having practically no resistance; the shunt circuit coil is wound with fine wire, having a resistance of 600 ohms. In the axis of these two coils a small iron rod, $\frac{1}{12}$ of an inch in diameter and $2\frac{1}{2}$ inches in length, moves in a vertical line between two guides; when magnetized it has one pole in the middle and the opposite at each end. The upward movement of the rod is limited by a spring resting upon a contact point, which is broken when the rod strikes the spring. The current from the positive pole of the generator passes through the coarse wire coil to the lamp and returns to the negative pole of the generator. The shunt circuit commences at the positive pole of the generator and passes through the fine wire coil to the contact screw on the coarse wire coil, whence it has two paths—the one offering no resistance through the spring resting on the contact screw which is connected to the negative carbon; the other, through the electro-magnet of 1,200 ohms resistance controlling the friction brake, and thence to the negative carbon.

The action of the apparatus is as follows: The carbon points being separated, the main circuit is open; the current therefore passes through the derived circuit via the screw point and spring to the fine wire magnet controlling the friction brake, thereby releasing the train of wheels and allowing the upper carbon to drop until it comes in contact with the lower carbon. When this occurs, the current passes through the main circuit, magnetizing the coarse wire coil and attracting the small rod, which in rising breaks contact with the spring and opens the circuit of the 1,200 ohm magnet controlling the brake; and at the same time energizes the solenoid surrounding the upper carbon rod, the armature of which immediately clutches the rod and lifts the carbon, thus establishing the arc. When the carbons become too far separated by burning, enough current will pass through the shunt to again release the upper carbon, and thus the two carbons are constantly maintained at the proper point of separation by these reacting forces.

THE MOLERA AND CEBRIAN ARC LAMP.

This lamp was invented for distributing the light in several directions by optical means, and consists of a regulator, with the luminous point inclosed in a polyhedric frame, with faces provided with Fresnel's lenses. The two carbons are supported by two systems of regulating carbon holders entering within the frame, and directed toward its centre. The carbon holders are fitted to the two ends of a tube filled with a liquid, in which they form pistons. At one part of this tube there is a kind of bellows, the movable part of which is provided with a plate of iron, which serves as the armature of an electro-magnet placed in the arc circuit. The attraction of this armature being proportional to the strength of the light current, exercises a greater or less pressure, which causes the carbons to advance proportionally to their consumption, and therefore maintains them in the centre of the frame. This pressure may, however, be regulated by means of an antagonistic screw. When the current is interrupted or weakened, the spring acts so as to bring the carbons nearer together; when, on the contrary, it increases, the inverse effect is produced and the carbons are separated.

On each face of the polyhedron, formed by the reflecting frame, abut tubes which may be placed in the streets, along buildings, or even under the floors, in order to distribute the light in a house. For that purpose it would suffice to fix a stout branch pipe with a properly inclined mirror at each change of direction.

THE GIROUARD ARC LAMP.

Girouard's lamp is a clockwork regulator somewhat resembling that of Foucault, but acting under the power of a relay regulator, is capable of being controlled from a distance. The system consists of an electro-magnet with thick wire, through which the current of the generator passes, and which acts on a double contact, and a lamp with a double clockwork motion, controlled by two fine wire electro-magnets. The current of the generator, after traversing the electro-magnet of the relay regulator, passes directly through the carbons of the lamp, their distance apart being regulated by an independent system which works by the influence of the two contacts of the relay regulator. When the current has its full strength, the mechanism controlling the separation of the carbons is set in motion, and when the current is weakened, the second clockwork mechanism is liberated, and this brings the carbons nearer together. In order to obtain this double action in opposite directions, Girouard used a spring barrel with a double movement.

THE BERJOT ARC LAMP.

The Berjot lamp employs two electro-magnets, one of which is wound with coarse wire and is placed in the main circuit with the carbon; and the other is wound with fine wire, and is placed in a derived circuit. The mechanism of the lamp is inclosed in a casing and the clockwork is supported by a frame, at the top and bottom of which are four flat springs, suitably regulated, and subject to the action, under varying conditions, of the two electro-magnets. One of these electro-magnets tends to raise the frame, the other to move the mechanism. The frame containing the clockwork carries the weight of the upper carbon holder, which is connected to a long rack gearing with the first wheel of the clockwork. A counter weight, acting in conjunction with the upper carbon holder, tends to pull down the frame containing the clockwork, which is resisted and held in a fixed position by the coarse wire electro-magnet. The carbon holder would always tend to fall if it were not held up by the clockwork, of which the last wheel is controlled by a brake. As this brake may be raised or lowered by the action of the fine wire electro-magnet, the rack of the upper carbon holder is free to move when this magnet is in action, the approach of the two carbons resulting from this action, which takes place when the arc is sufficiently weakened to give to the fine wire electro-magnet an excess of power over the other. The approach of the carbons is moreover effected conjointly with the locking of the case containing the clockwork, but when the carbons are so near together as to restore the strength of the current at the arc, the coarse wire magnet raises the apparatus so that the fine wire magnet releases the brake and prevents the clockwork from moving until the arc again becomes weakened.

THE STANDARD LAMP FOR FRENCH LIGHTHOUSES.

Figure 253 represents the lamp which has recently been adopted for the French electric lighthouses. It is a combination of the Serrin and the Berjot lamps, comprising the two electro-magnets of the Berjot lamp, the armatures of which form an internal core, one magnet having coarse wire and placed in the main circuit, the other fine wire and placed in a derived circuit. The former acts on the articulated frame carrying the lower carbon; the other acts on the brake which controls the clock train. S is the coarse wire electro-magnet acting through the lever Q on the articulated frame or cage, the two springs R and R′ tending always to lift the cage. The tension of these

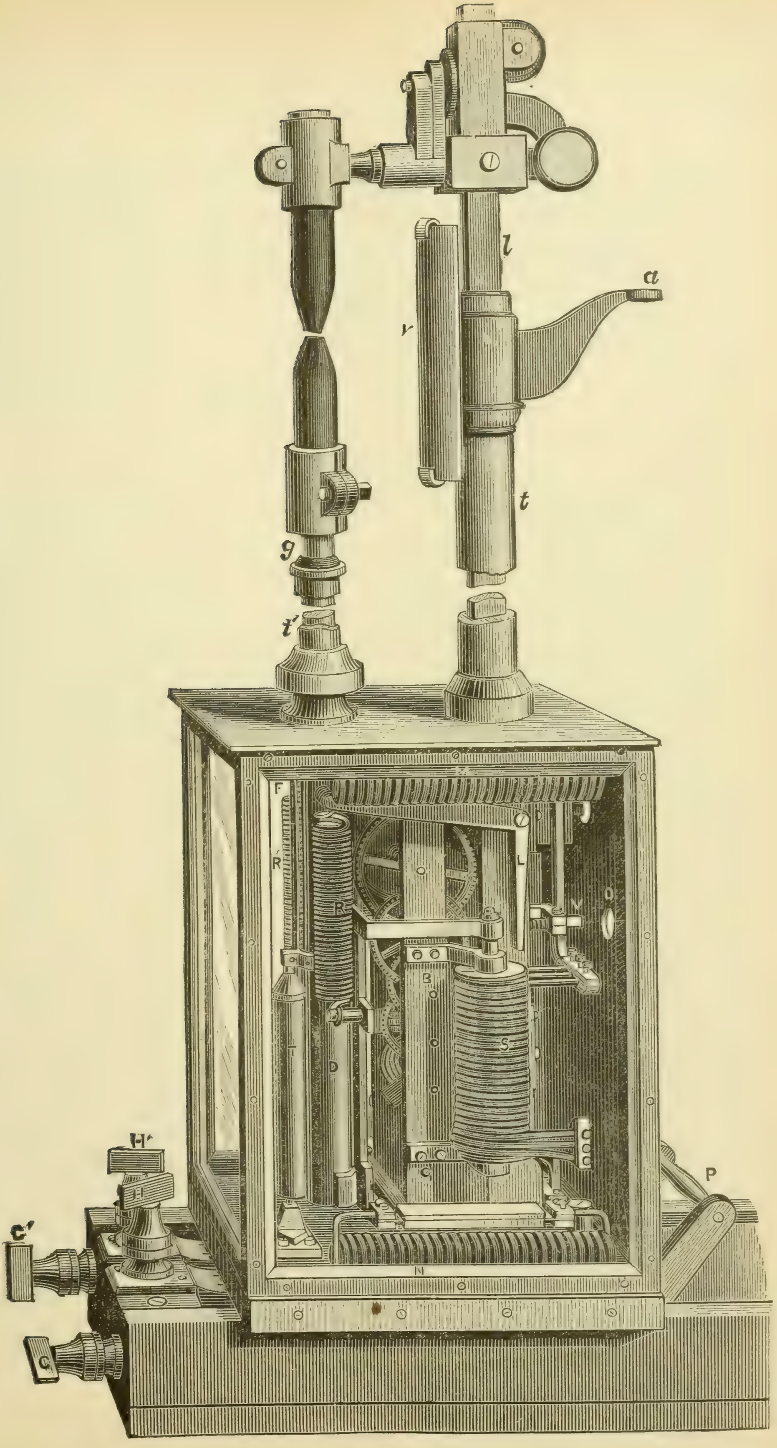

Fig. 253.

springs is regulated by the bent lever L hung to the frame of the lamp, and the position of which can be altered by the screw V, which can be turned by a key passing through a hole in the casing. The fine wire coil is not shown in the drawing, but it occupies a position corresponding to that of the electro-magnet S on the other side of the clock train. The connection between the two carbon holders and the first spindle of the train is effected by means of a steel ribbon, F, attached to the lower ends of the two rods *g* and *l*, the lower and upper carbon rods respectively. This ribbon is led over several pulleys and passes round the greater part of the circumference of a wheel on the first axis of the clock train, so that there should be no slip between the ribbon and the pulley. The rod *g* slides in the tube D fixed to the articulated frame, and this tube has a vertical slot formed in it to allow the ribbon to be attached. This mode of connecting the two rods supporting the carbons, which replaces the chain of the Serrin regulator, allows the carbons to be set at their right height by a slight slipping of the ribbon. Another peculiarity in the lamp is the mode of connection adopted for the internal mechanism. The current from the large cable conductor is led to the upper carbon from the rails and the non-insulated part of the lamp. From the lower carbon it returns to the two insulated terminals H and H′, passing partly through the articulated cage and partly through the electro-magnet S. The connections between the pieces to which the current arrives are made with four spirals of thick copper wire, nickel plated; they are shown at M and N, placed above and below the coarse wire magnet S. The tube D carrying the rod *g* is not insulated from the articulated cage, but the latter is insulated from the rectangular bar by which it is carried. This arrangement is convenient in construction, because it is more easy to insulate a rectangular bar than a round piece like the tube D. An air-pump, T, serves to deaden the motion of the cage, and prevents any violent oscillation. The ingenious details of the porous plate *v* must be noticed. When large carbons like those necessary for lighthouses are employed, the turning piece *a*, that serves to regulate the height of the arc, becomes heated as well as the rods *t′* and *t* and the different parts exposed, often causing them to bind. To avoid these inconveniences, a porous clay shield, *v*, is introduced as shown. When the upper carbon holder has reached the end of its travel, it acts laterally on a small inclined rod which draws back a spring and cuts off the connection with the fine wire electro-magnet, so that it cannot be injured by the passage of too strong a current.

THE GULCHER ARC LAMP.

The Gülcher lamp, which is very highly appreciated in Europe, is shown in perspective in fig. 254. It contains no clock-work, and the regulation of the carbons is effected by a single electro-magnet. The two carbon holders are connected by means of a cord passing over a pulley R; the upper one, whose rod T T′ is of iron, is heavier than the lower, and tends to descend at the same time that it raises the latter. E is an electro-magnet which is free to move up and down upon its trunnions. The poles of the electro-magnet are curved, forming parts of a circle, the centre of which is on the axis of the trunnion. The pole on the right extends downward and terminates in a projection, beneath which is a small iron block attached to the case of the lamp. The rod of the upper carbon holder moves before one pole of the electro-magnet, while a small iron block is pressed against the other by a spring whose tension is regulated by a lever. Passing through the top of the casing is the screw V, which terminates in a spindle, against the lower end of which the electro-magnet rests when no current is passing. This position of the magnet is secured by means of the spring which is connected to the angle lever pivoted to the insulated bearing M. The upper end of the spring bears against the screw B, and the position of the spring and its pressure against the trunnion is regulated by means of the screw *r*, which is insulated from the angle lever. The current from the positive pole of the generator is conducted to the bearings M, which are insulated, passes thence to the trunnion and coil to the core of

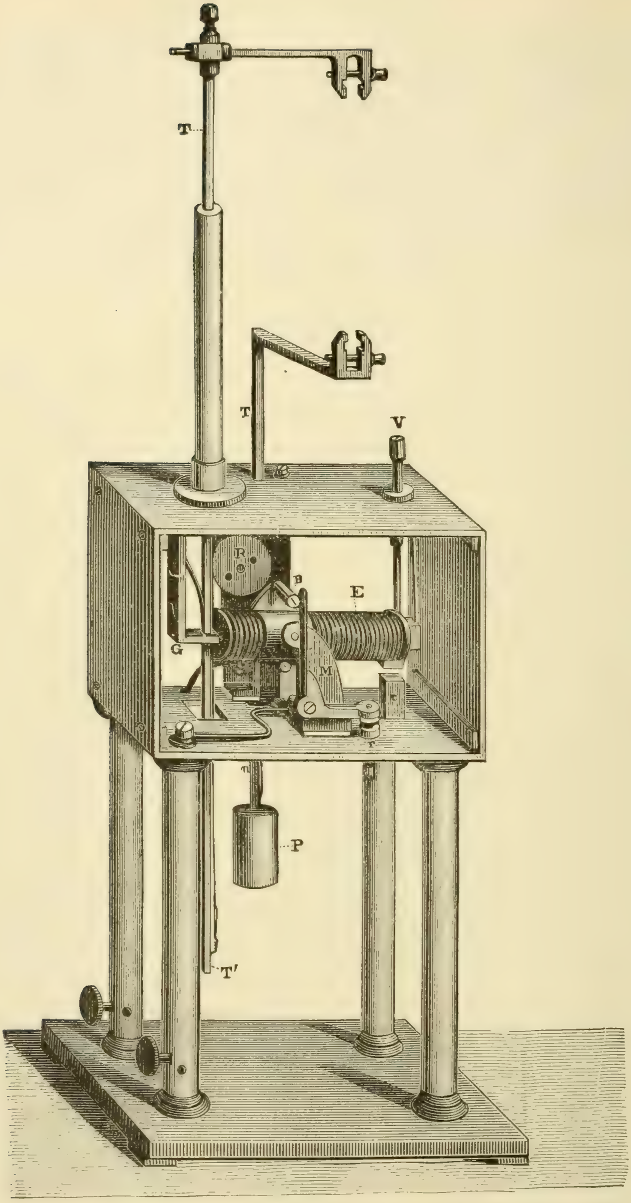

Fig. 254.

the electro-magnet, whence it flows, partly through the spring which is in contact with the end of the magnet, and also in metallic connection with the case of the regulator, and partly to the rod T T′, in contact with the other end of the magnet. Finally the two currents unite, and, passing through T T′, flow through the carbons, the lower carbon holder, and thence to the negative pole of the generator.

The operation of the regulator is as follows: As soon as it has been connected with the generator, the electro-magnet E attracts the rod T T′ of the upper carbon holder, and at the same time the projection of the other pole of the magnet is attracted to the fixed piece of iron at the bottom of the casing, thereby causing the electro-magnet to turn on the trunnions. By this movement the carbon holder T T′ is necessarily lifted, because of the contact with the curved face of the pole piece, the motion being far steadier and more uniform than could be imparted by a rack and pinion; the two carbons are thus separated and the voltaic arc produced. As the carbons burn away, and the distance between them becomes greater, the resistance increases, and consequently the power of the electro-magnet diminishes, the projection of the pole piece becomes further removed from the piece of iron under it, the carbon points approach each other, and the magnet continues to turn on its trunnions until it is arrested by the stop V, the position of which has been carefully adjusted. As soon as this condition has been established the magnet has no further movement, the carbons continue to burn until they are at that distance apart corresponding to the greatest intensity of light. As soon, however, as further consumption increases the distance, the attractive power of the magnet becomes too small to enable its pole to hold the bar T T′, and the bar begins to slide down, until the carbons are brought nearer together, and the power of the magnet is increased so that it again holds the bar T T′ and prevents it slipping further. If the bar continued to fall, the power of the magnet would increase until the pole piece would be drawn down to the piece of iron beneath, and the preliminary process above described would be repeated. In practice, however, it is found that after the lamp has been started the magnet remains stationary, the consumption of the carbons and the weight of the rod. T T′ being sufficient through the intermittent action of the magnet to secure the automatic working of the lamp. The face of the left pole and the rod T T′ are covered with thin brass to prevent adhesion, as are also the other pole and the small iron block resting against it. This block serves as a brake upon the action of the magnet when the lamp is started, and secures a soft and easy movement. The rod T T′ is constantly pressed against the magnet by a spring attached to the frame G.

THE WOOD ARC LAMP.

The popular and ingenious electric lamps designed by Mr. James J. Wood, and manufactured by the Fuller Electrical Company, belong to the differential solenoid type, so generally employed in the construction of the modern electric regulator. Fig. 255 is a general view of the Wood standard arc lamp.

The framework of the lamp is insulated and water tight. The binding posts *a a*, are so situated that the circuit wires enter at the top of the lamp, so that if the connections become loose from any cause, they will always tend to make contact, as the weight of the wires will keep them in position. These binding posts also serve as bolts to hold the insulated roof plate in position. The hand switch, *b*, is similar to the key of a gas burner, and can be operated from below in a similar manner to turn the light on or off. The ornamental cup, *c*, at the bottom of the lamp, is so arranged that the carbon dust, which accumulates as the carbons are consumed, falls into it. It is held in position by a bayonet joint to facilitate its removal for cleaning. The positive carbon holder is fitted with a universal adjustment, *d*, for bringing the carbon points in line.

Fig. 256 is a perspective view of the interior of the lamp, and fig. 257 is a diagram illustrating the direction taken by the cur-

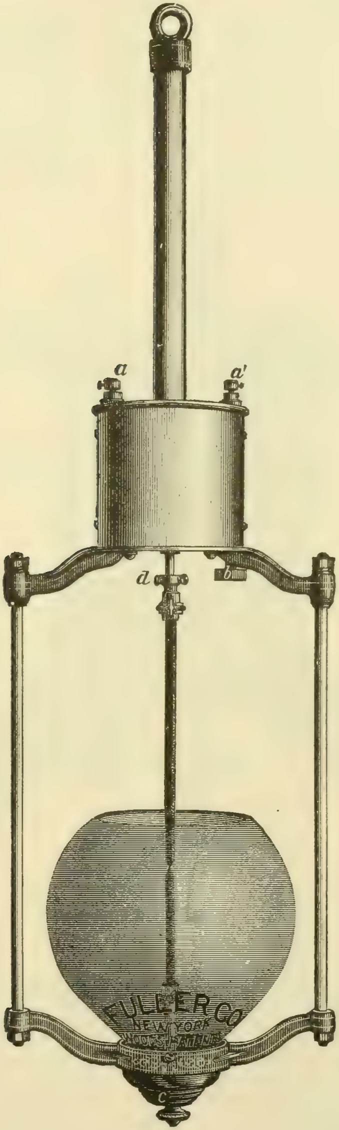

Fig. 255.

rent in passing through the lamp to produce the light, and also the action of the automatic cut-out, operated by an abnormal attraction of the magnets in case the lamp fails to feed. The current enters at the upper left-hand corner, marked *a*, following the direction of arrows to the feed-rod *e*, to the positive carbon, through the arc, thence through the negative carbon, and back

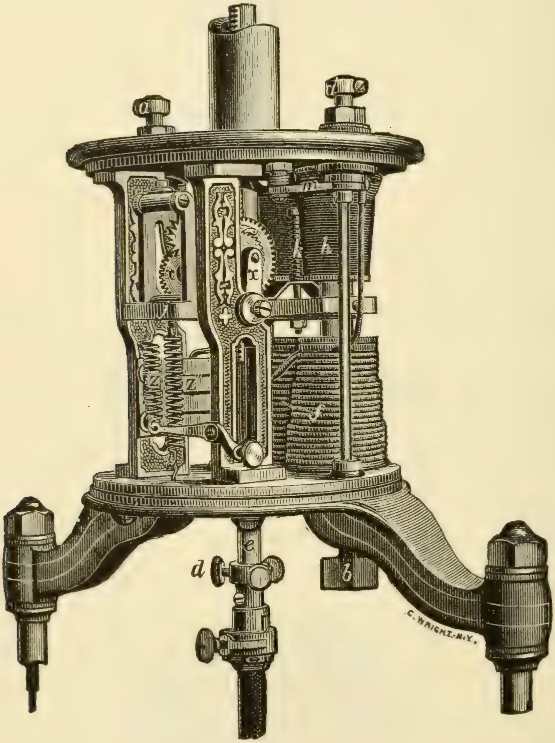

Fig. **256.**

through the heavy connection around the magnets *f f*, thence to the right of the figure and out to the next lamp. The action is as follows: The carbons being in contact, the current will flow in the direction shown by the arrows, through the carbon rod *e*, through the carbons, thence through the magnets *f f*, and thus attracting the armature *i*, which through the agency of the lever *j*, as shown in fig. 256, will produce a separation of the carbons. The magnets *h h*, in the shunt circuit around the arc, have a very high resistance, so that when the carbons are together, practically no current flows through *h h;* but the instant the carbons are separated, the current divides inversely as the resistance of the arc and shunt circuit, thus causing a greater proportionate flow of the current through the fine wire coils *h h*, which proportion will increase as the carbons are consumed, until the arc becomes of normal length. When this occurs, the attractive force of both magnets is balanced. If the arc increases in length, the attractive force of the magnets **h h** will preponderate, attracting the armature *i* in that direction, and causing the carbons to feed. In case of a failure of the carbons to feed from any cause, the magnets, *h h*, will continue to increase in strength

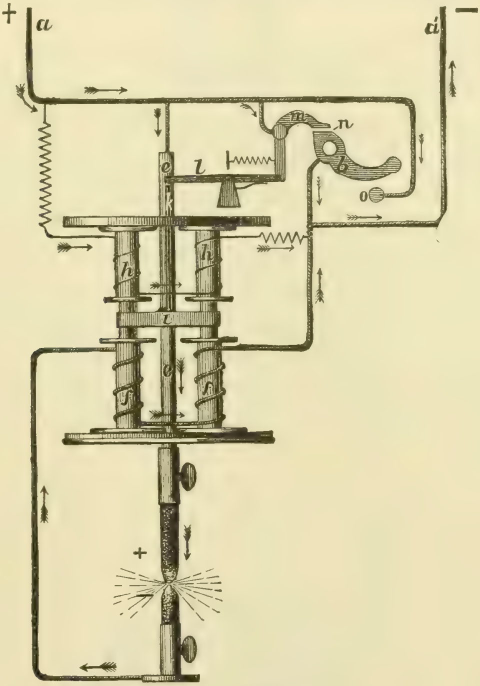

Fig. 257.

until the pin *k* comes in contact with the lever *l*, tripping the cut-out lever *m*, closing the contacts *n*, and automatically cutting the light out of circuit. In case it is desired to switch the lamp out of circuit by hand, the switch *b* is moved so as to close contact with the knob *o*, which sets the cut-out so as to be again operated by the magnets, when the lamp is again put in circuit. These movements are so arranged that no contact is broken until another has first been formed, thus avoiding all sparks and consequent injury.

The object of the adjusting spring, *z*, is to govern the length of the arc, which is easily regulated by turning the screw, z'.

The permanent balancing spring shown at the right of the adjusting spring, in figs. 256, 259 and 262, is used to preserve the adjustment so as to continue the lamp in operation even when the spring, *z*, is improperly used, as sometimes occurs from ignorance or carelessness.

The comb spring, z'', is employed to insure a positive contact with the feed rod, thus maintaining the path of the current without depending upon the feeding mechanism therefor. At *x* will be seen a small train of clockwork, the object of which is to retard the downward movement of the rod, *e*, thus securing a steady light.

Fig. 258 is an exterior view of Wood's automatic duplex lamp, designed for all night illumination. The burning capacity of this lamp is from 14 to 16 hours without replacing the carbons. The general construction of the frame as to insulation, convenience and appearance is the same as that described in fig. 255. The principal difference consists in the fact that this lamp is designed to feed two carbons consecutively instead of one.

Fig. 259 is a perspective view of the interior construction of this lamp, and fig. 260 is a sectional and plan view, showing the main features of the feed mechanism, cut off switch and methed of insulation. The action of this lamp is as follows: The feed rod, *e*, is the rod which first comes into action, the rod e', being held in position by the latch lever, *p*. As the carbon is consumed in the rod, *e*, it feeds forward until near the

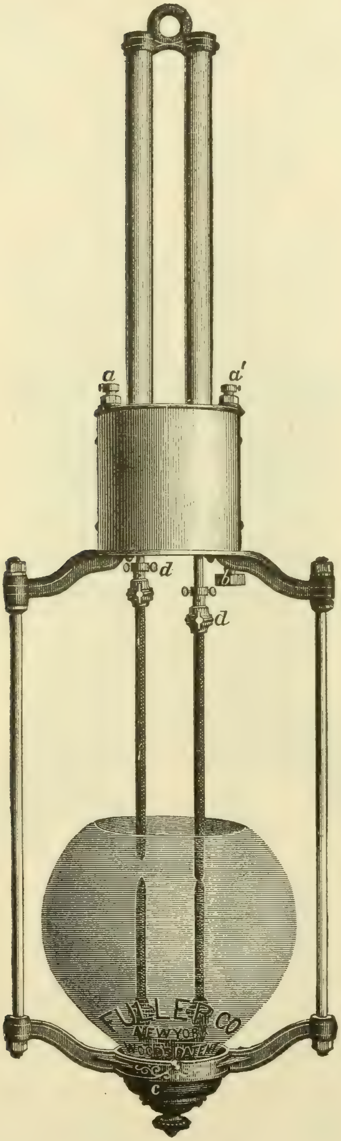

Fig. 258.

end of its course when the pin, *q*, comes in contact with the lever, *p*, and trips the rod *e'*. The instant that this occurs, the rod, *e*, having reached the bottom of its travel, leaves a space between the carbons equal to the length of the arc. After the rod, *e*, is tripped, it will feed forward until the carbons on this side of the lamp come in contact; the current will then pass through this set of carbons, which offer the least resistance, breaking the arc and extinguishing the light in the former set.

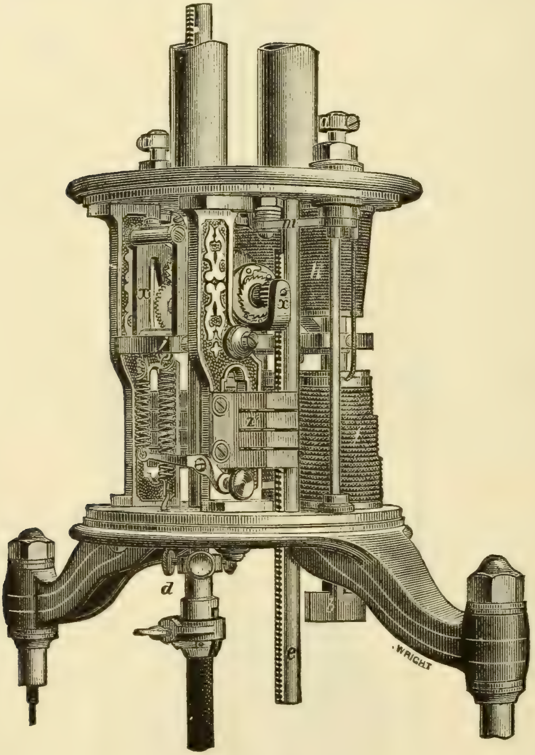

Fig. 259.

A peculiar feature of this lamp is, that while both feed rods are connected positively together with a single movement—the lamp having but a single set of magnets—there is no instant in its whole operation when both rods are acted on at the same time. This result is accomplished in the following manner: The pinions, r, r', gear into their respective rods, e, e', and are fastened to a ratchet wheel, s, s', which gears into the driving disks, t, t'. These disks fit loosely on the spindle, u, having a

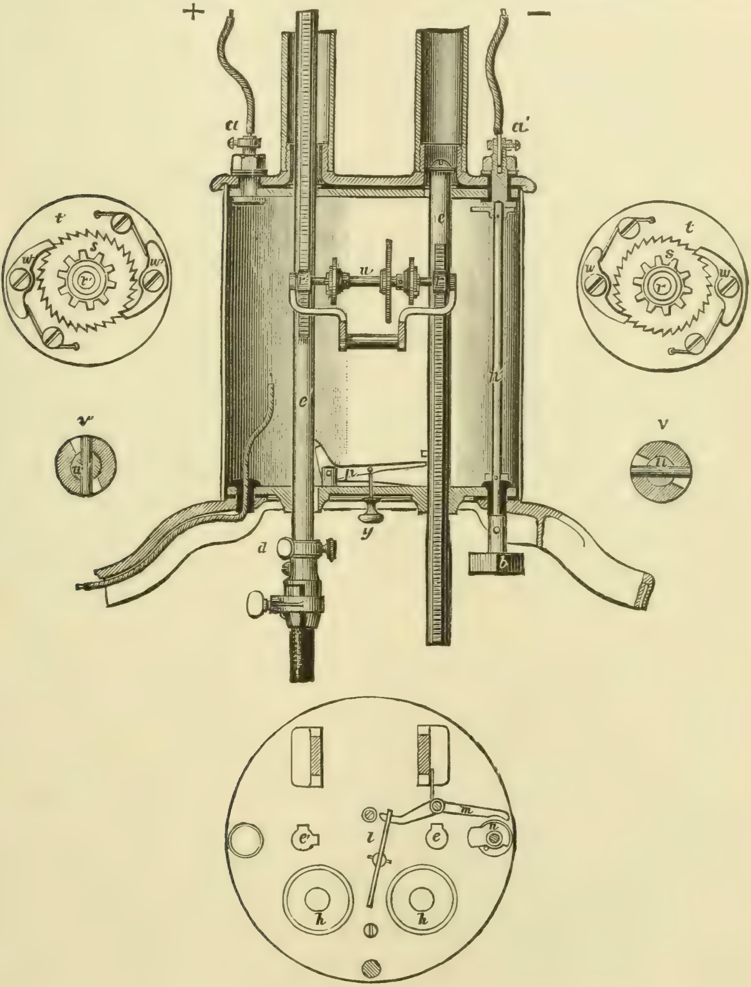

Fig. 260.

certain amount of motion around the axis of the spindle, which motion is about equal to that produced by the separation of the carbons.

If we consider the rod, *e*, to be feeding its carbon forward, and the rod *e′* to be latched, as shown in fig. 260, it will readily be seen that the pinion *r* becomes the driver, and will revolve the disk *t*, taking up the play as shown in the section *v*, transmitting a rotary motion to the spindle *u*, which in turn will cause the disk *t′* to revolve, taking up the play in the opposite direction, as represented in the section *v′*. Now, as will be readily seen, the pinion, *r*, at the right hand of the figure, being the driver, the disk *t′* at the left hand of the figure will be driven around the ratchet wheel and pinion *r′*, causing the pawls *w*, *w′*, to slip, as the pinion, *r*, is geared directly to the feed rod *e′*, which rod being latched in its upright position prevents the pinion from revolving without disengaging it for an instant from the main train *x*, shown in fig. 259. The advantage of this will be appreciated if we consider that if one pinion were disengaged while the other was operating, there might be a time when it would be difficult to reverse the connections without causing the teeth to strike on the tops of each other, or allowing the rod to fall too far. When the rod *e′* is tripped so as to set it in motion, the action is reversed.

The purpose of the button, *y*, is to facilitate cleaning and replacing carbons in the lamp. By pressing it downwards, both carbon rods are brought into simultaneous action.

Fig. 260 is a sectional and plan view, showing the action of the hand switch and the automatic cut-out. In the figure, *n* represents a cam shaped piece, which is in direct connection with the spindle *n′* and the key *b*, which compose the hand switch. The action of this is as follows: The end of the spindle *n′* is seated in a bearing at the inside of the negative binding post *a′* which is insulated from the framework of the lamp, and is of negative polarity. When this is in the position shown in the figure, there is a space between this cam and the cut-out lever *m*. This cut-out lever is in direct connection with the positive binding post *a*. By turning the key *b* one quarter, the projection of the cam, *n*, is brought in direct connection with the lever *m*, switching the lamp out of circuit; by turning the key in the opposite direction, these connections will be broken and the lamp again switched in circuit. The operation of the automatic cut-out shown in fig. 257—in case of failure of the lamp to feed from any cause, or when the carbons are consumed—is produced by tripping the latch *l*, and allowing the lever, *m*, to automatically close contact with the cam, *n*.

All that is required to put this lamp back in circuit, after automatic extinguishment, is to turn the key, *b*, in the direction to switch the lamp out, and then back to switch it in, as before described.

Fig. 261 is an exterior view, and fig. 262 a perspective view of the interior construction of Wood's focussing lamp. Fig. 263 shows the method of insulation and feed connections between the positive and negative carbon carriers. Fig. 264 shows a plan of the feed connections, and Fig. 265 shows an enlarged view of the feed spindle for feeding the negative carbon, and also the arrangement of the insulation. This lamp is constructed so as to operate singly, or in series with other standard single or duplex lamps. The improvements in this lamp are of an altogether novel description, and it will be necessary, therefore, in order to thoroughly appreciate them, to turn for a moment to a consideration of the defects of the lamps designed for the same purpose, that have preceded it; the means employed by their constructors to correct or remedy them; the cause of the failure of such attempts, and a description of the means which have been devised by Mr. Wood to overcome them. In the earlier forms of lamps, the positive carbon carrier, feeding by gravity, caused a train of clock-work to be set in motion, which wound up a chain insulated and connected with the negative carbon carrier in such a way as to cause the latter to be fed forward. The objection to this device was, that in case the negative carbon carrier was lifted or pulled up in cleaning the lamp, through carelessness, the chain was liable to quit the pulley,

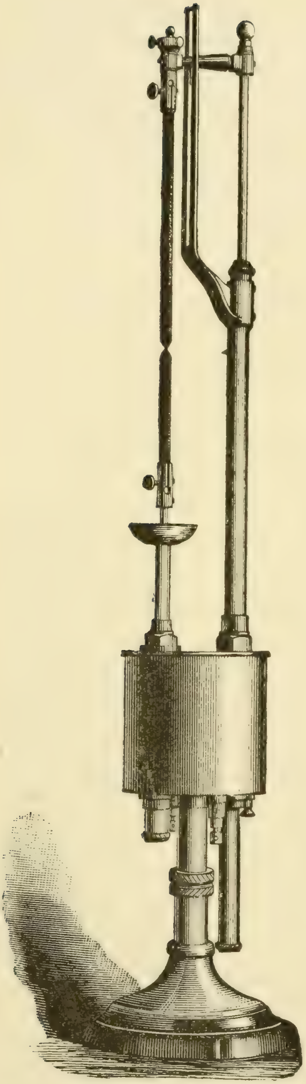

Fig. 261.

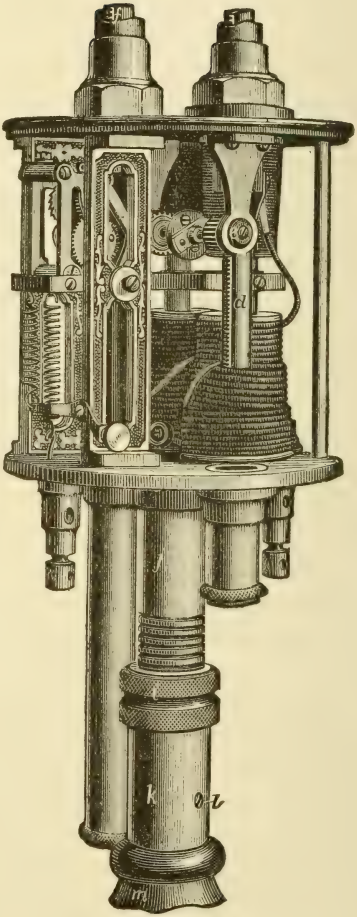

Fig. 262.

come in contact with other portions of the lamp, short-circuiting it, and in many instances melting the chain and ruining the mechanism. To obviate this evil, focussing lamps have been designed, with a cord to replace the chain. While this cord will not short-circuit the lamp, it leads to many mishaps and annoyances, as, for example, it is liable to be thrown off the pulleys or sheaves which guide it, by the careless lifting of the carbon holder,

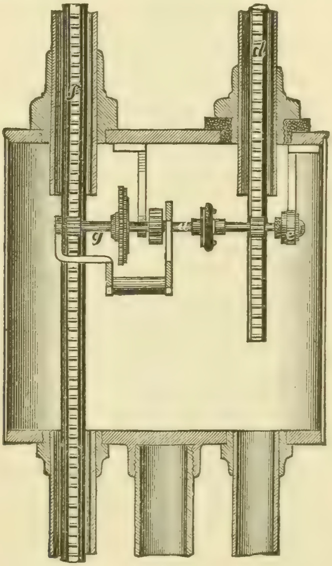

Fig. 263.

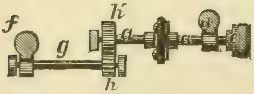

Fig. 264.

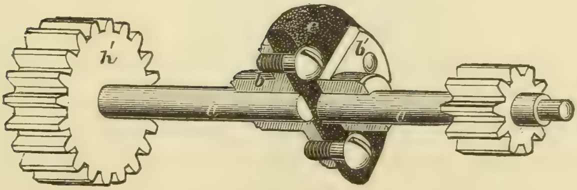

Fig. 265.

or to be broken by pressing down the negative carbon holder; in which case the strain necessary to move the positive carbon holder, which is about three times as heavy as the negative, and has to travel twice as far, is borne by the cord. As this strain is about six times greater than that required in its normal action, it is liable to, and often does, break. To remedy this defect, focussing lamps have been constructed with gear connections, the wheels being insulated from the spindles carrying them; but as quite a number of these had to be insulated, and the wheels were necessarily small, it was found that the insulation was liable to shrink, and that the required strength could not be attained, so the plan was eventually abandoned.

Figs. 262 to 265 illustrate the method adopted to remedy these defects. As will be seen from Figs. 263 and 264 the carbon carriers of this lamp are geared together with positive connections, the pinions and wheels being fastened rigidly to the spindles. The insulation is accomplished by a disk of hard rubber, forming a coupling of unique construction, represented in Fig. 265. It will be seen from this figure that the spindle, *a*, is cut in the middle, leaving a space of about an eighth of an inch. Each end of the spindle is fitted with a cross-arm *b b*,′ which is screwed to a hard rubber disk *c*, in such a manner that the cross-arms, *b b′* stand at right angles to one another on each side of the disk, *c*. The screws pass through the rubber and screw into the arms *b b′*. This arrangement results in a perfect insulation, also leaving the spindle as strong as if it were in one continuous piece; the connections being such that they are not liable to be interfered with by shrinkage or change of temperature.

Figs. 263 and 264 show the position which this spindle occupies in the lamp; *d* represents the negative carbon carrier, which is insulated from the body of the lamp; *e* represents an insulated bearing, in which one end of the spindle, *a*, revolves; *f* is the positive carbon carrier, and *g* is a spindle which connects it with the spindle *a*; *h h′* are two gear wheels having a relative proportion of two to one. The two feed rods are so connected together as to move forward in their respective proportions, the

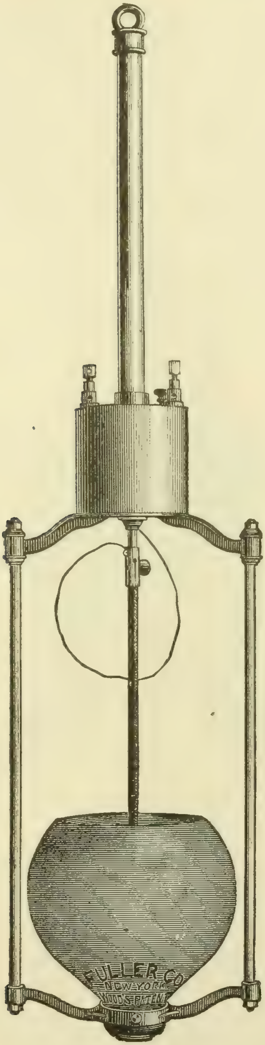

Fig. 266.

whole being so rigid in its construction that either carbon carrier can be forced in either direction without in any way endangering the operation of the feed mechanism, or injuring the insulation. The direction which the current takes in passing through this lamp is similar to that described in fig. 257. Referring to figs. 261 and 262, it will be seen that the base of this lamp is so constructed as to provide an adjustment for raising or lowering the whole mechanism. In order to always maintain the light in the focus of the reflector, the body of the lamp rests upon the tube, *j*, on which the knurled nut *i* turns; this nut being turned to the left to raise, and to the right to lower the lamp. This tube *j* slides into a tube *k*, and is held in position by the screw *l*, which fits into a slot in the tube *j*. The nut *i* is held in its position by a screw not shown, the end of which fits into a groove around the tube *k*, which sets upon the ornamental base *m*.

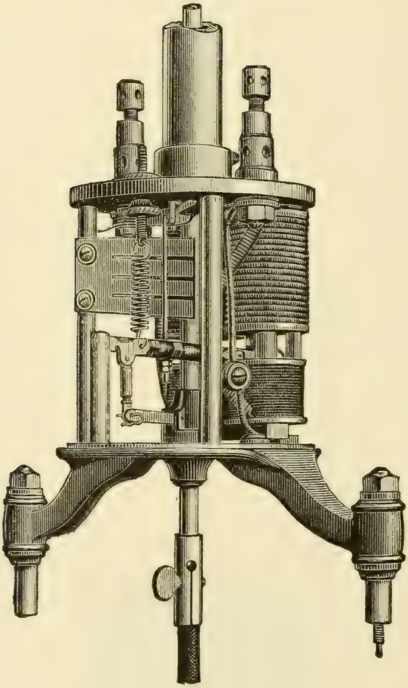

Fig. 267.

Fig. 266 represents the exterior, and 267 is a perspective view of the interior of Wood's semi-incandescent lamp; and fig. 268 is a diagram showing the direction taken by the current in passing through the lamp, and also the action of the automatic cut out which is operated by repulsion. This lamp was designed by Mr. Wood to be used in series with the standard arc lamps, or for separate use where a greater distribution of light is desired, and the volume of light produced by the standard lamp is not required. It is of low resistance—about two ohms—the standard lamp having about four and a half ohms, and produces a considerably smaller light. About twice as many of these lamps are operated from the same machine as of lamps of standard illuminating power.

The operation of this lamp is as follows: Referring to fig. 268, it will be seen that the current enters at the upper left hand corner at the wire marked +, following the direction of the arrows down the rod *a* to the positive carbon, thence to the negative carbon, and back through the magnets *bb′* which are in the main circuit, and thence out through the wire marked — to the generator or to the next lamp in series. The current divides itself between the resistance of the arc and the resistance of the shunt magnet coils *c c*. These coils are wound in a direction so as to set up a polarity in the cores similar to that of the current flowing through the magnets *bb′*. The action is as follows: Imagine the carbons in contact, and the current from any source sent through the lamp; after passing through the carbons it will pass through the solenoid coils *bb′* which are in the main circuit, causing them to attract the shunt magnet *c′*, which is of a horse shoe form, and acts as an armature for the main solenoids *bb′*. This action produces the separation. As the carbons are consumed, a greater proportion of the current will be diverted through the shunt magnet coils *cc*, in a direction tending to neutralize the magnetic influence of the solenoids *bb′*, allowing the magnet *c′* to gravitate downwards, to produce the feed of the carbons. In case the carbons should fail to feed and the arc become abnormally long, a still greater proportion of current will be diverted through the shunt magnet coils *cc*, which will polarize the cores similar to the polarity of the current flowing through the solenoids *bb′*, and cause them to repel or force out the magnet armature *c′*. If the lamp then fails to feed, they will continue to force out the armature, which will come in contact with the lever *d*, tripping it and allowing the contact points *e* to be automatically closed, switching the light out of circuit.

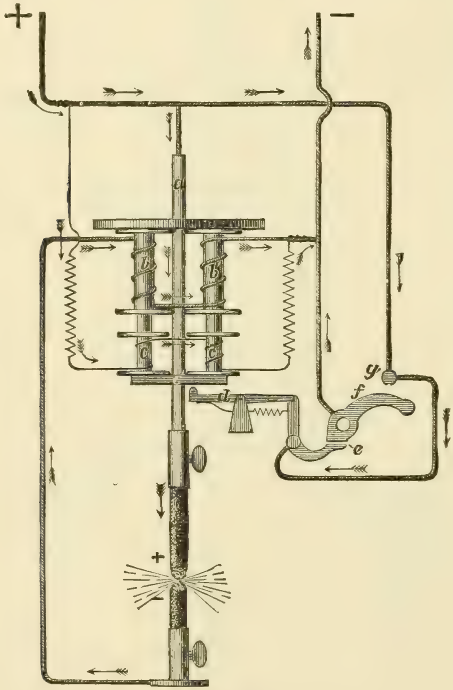

Fig. 268.

When it is desired to switch the light out by hand, all that is required is to move the hand switch *f*, so that it will close contact with the knob *g*. The reverse operation will again re-establish the arc. The precise arrangement of parts in this lamp is shown in fig. 267.

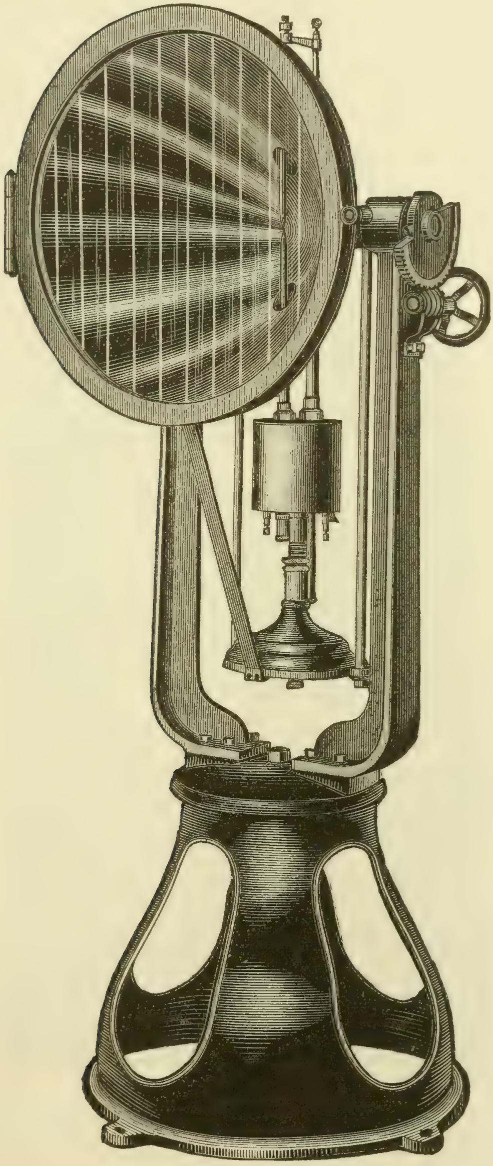

Fig. 269.

The marine projector, fig. 269, is used in connection with the focusing lamp in cases where it is desired to throw the light in different directions, and is designed for use on vessels navigating rivers, lakes and harbors. It is provided with a hand wheel which engages into a sector or worm-wheel, by the use of which

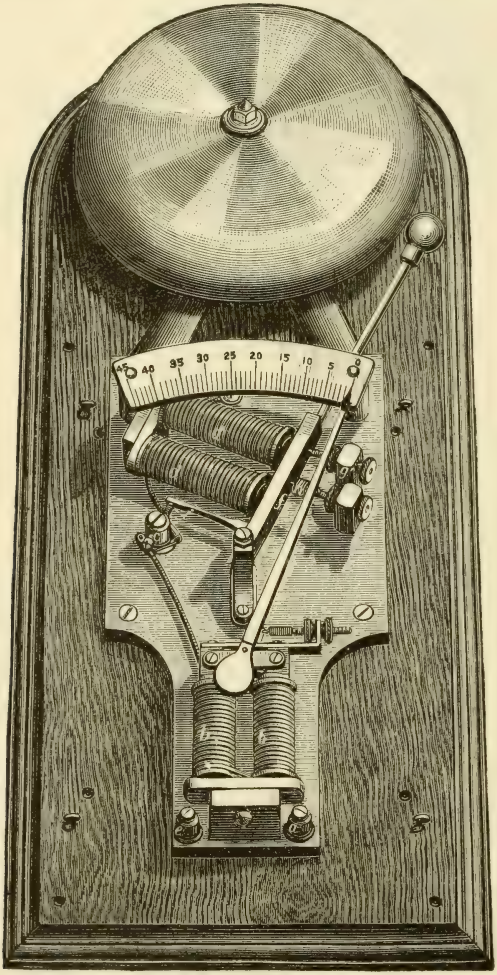

Fig. 270.

the light is thrown up or down, or retained in any position desired. It also swings on a bolt in the centre of the uprights, so as to throw the light in any required direction laterally. This projector is arranged with a camera in each trunnion, on which an image of the carbon points is reflected, so that when the light is seen directly in the centre of the object-lens the carbons are in focus.

Fig. 270 represents the interior construction of Wood's indicator and alarm, designed for use where the lights are operated from central stations, so as to enable the users to turn them on or off at pleasure. The operation of this apparatus is as follows: Imagine the current as entering at the binding-post, *a*, passing through the magnet coils *b b*, thence to the stud *c*, thence around the magnet coils *d d*, and back through the frame-work of the instrument to the binding post *e*, thence through the carbons to the generator. The current, in passing through the magnet coils *b b* and *d d*, strongly magnetizes their cores. The cores of the magnet *b b* have polar extremities, formed with eccentric faces, so that they tend to attract the armature, carrying with it the pointer in a direction so as to produce a deflection of 45° on the scale. The armature *f* of the bell is held against a stop *g* by the spring *h*, which balances the attractive force of the magnet when the current flowing through the coils *d d* is normal.

Let us assume that this indicator is connected in the engine-room with an electric light circuit, where several lamps are in operation, and the current flowing through the instrument is the standard current necessary for this number of lights. Then, in case of the extinguishment of one or more of the lamps, the resistance of the circuit will be diminished, the quantity of current increased, and the pointer of the indicator will move past its normal position, due to an increased attraction of the magnets *b b*. The magnets *d d* will also increase in strength, overbalancing the spring *h*, which holds the armature against the stop-screw *g*, attracting the armature and striking the bell. When the bell is struck, the contact points *i* are closed, which shunts a portion of the current from the magnet coils *d d*, causing it to release the armature *f*. This operation will be repeated until the engineer in charge sets the regulator on the machine so as to reduce the current.

In case lights are turned on, the resistance of the circuit will be increased, the pointer will then fall below its normal position, the engineer will then set the regulator so as to supply the lamps with more current until the pointer comes back to its original position. In case of a short circuit occurring on the line, so as to cut out several lamps, the bell will ring violently, and continue to do so until the extra current required for those lamps has been turned off. An important feature of this device is, that it is operated by the same current as that which operates the lamps, and does not require the aid of a local battery.

THE BROCKIE ARC LAMP.

The Brockie regulator readjusts the distance of the carbons intermittently by automatically interrupting the circuit during the fraction of a second. The positive carbon holder slides on two guides; the negative carbon is fixed, consequently the lamp has a shifting focus. A derived current traverses a branch circuit leading to an automatic commutator, and also to an electro-magnet, whose armature is intermittently attracted, and through the action of a clutch, permits the carbon to descend at such times as the armature is released by the magnet. The upper carbon then falls on the lower one, but only momentarily, as the action of the commutator restores the action of the electro-magnet, the armature is again raised, and with it the clutch lifting the carbon, re-establishing the normal arc. The commutator upon which the successful action of the lamp depends is connected with the branch circuit by means of a toothed wheel (driven by a worm, which is caused to rotate by the generator shaft) and by a pawl. On the toothed wheel lies a small disk and a projecting pin. Except at intervals, the pawl lies on the face of the disk, and the circuit is closed; but at fixed periods, say of one minute, the pin comes in contact with the pawl and raises it from the disk; the circuit is, however, still maintained, until in its revolution the pin passes clear of the pawl, and the latter falls on to the face of the disk, the period of interruption of the circuit being that occupied by the pawl in falling on to the disk, when it is immediately restored. This very minute period suffices to allow the armature clutch and carbon to fall.

In another form of the Brockie lamp two solenoids are employed, one in the main and one in a shunt circuit. The second magnet releases, retards or stops the feeding train, while the first tightens or slackens the spring against which the second acts, so that when a strong current exists in the main circuit, the first magnet, besides directly lengthening the arc, will tighten the spring. By this arrangement the lamp becomes self-regulating, and may be worked with currents of varying strength without adjustment or regulation. When the solenoids are thus arranged, and the main current is diminished from any cause, the solenoid in the main circuit will reduce the tension of the feeding spring, and thus compensate for the simultaneous weakening of the shunt magnet, while at the same time it brings the lower carbon a little nearer the upper one, reducing the length of the arc and adjusting the feeding gear to the desired strength of the current. The arc of the main circuit solenoid is of iron in the upper part only, and is pulled downwards against a spring. The shunt solenoid, which is situated directly above the other, actuates a brake upon the upper carbon holder. The lever of this brake plays between two stops, the lower of which forms an abutment, which allows the lower solenoid arc, as it moves up and down, to diminish or increase the tension of the feeding spring. The descent of the carbon is retarded by a dash pot or a train of wheels.

THE VARLEY ARC LAMP.

This lamp, which is designed for the employment of the inventor's flexible carbons, contains a holder into which the carbon candles are coiled.

The candles are brought through conducting guides, by means of which the ends are brought together, to produce light. For feeding the carbon forward at the rate requisite for its consumption, conducting rollers or propellers are used, and a magnetic regulator determines the length of the arc. The centralization of the latter is effected by variable resistance. The feed is regulated by clockwork, controlled by an electric current, the rate of feed being determined by an automatic propeller, through which the current passes.

Mr. Varley's carbons consist of flexible filaments made into a thick, rope-like bundle, and when burning in an arc lamp the result is said to be curious and novel. Instead of the dazzling point of light, emitting rays from a very small area, and looking like a brilliant star, the Varley light is more like a planet, presenting a disk of appreciable diameter; most of the luminosity coming from the arc itself, and not from the ends of the carbons. The diameter of the carbons has to be regulated according to the strength of the current, otherwise they burn away too rapidly; but when properly proportioned to the current they are said to burn away more slowly than hard carbons.

The flexible carbons are made by taking pieces of rope or plaited cord, and soaking them in paraffine or crude ozokerite—an inexpensive fossil wax—and then carbonizing them in a crucible filled with hydrocarbon vapor. The firing is continued for ten or twelve hours, and the heat is intense enough to soften wrought iron to a plastic state, slightly below its melting point.

THE WILDE CANDLE.

The Wilde candle (fig. 271) is composed of two carbon pencils, twenty-two inches long and one-sixth of an inch in diameter, held in a vertical position, parallel to each other, and separated by an air space of one-sixth of an inch in width. Each pencil is held between two jaws, which are made to pass against it by a hoop-shaped spring B, embracing both. The pair of jaws corresponding to the right-hand carbon in the figure are supported on a vertical arm fastened to the base of the

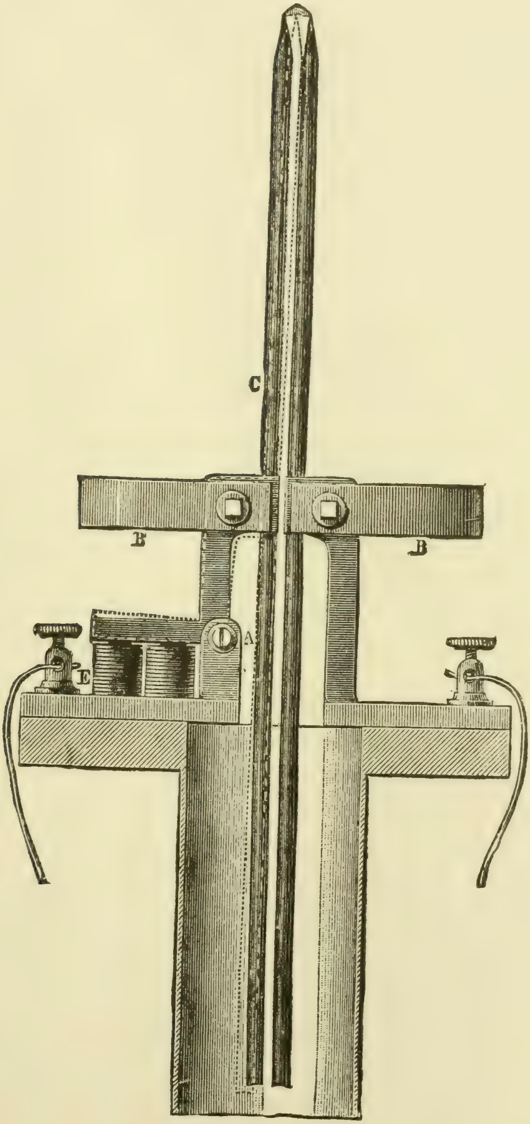

Fig. 271.

lamp, and are in connection with one pole of the lamp. The arm which carries the jaws, holding the other carbon C, oscillates on a pivot A, precisely like a bell crank lever. From this arm the circuit leads to the electro-magnet E and thence to the binding post. When no current is passing, the weight of the carbon C causes the bell crank lever to move, and its carbon C to tilt until the two carbons touch at their upper ends, this inclined position of the carbon C being represented in the figure by the dotted lines. As soon as the current is put on, the electro-magnet E attracts the horizontal portion of the bell crank lever, which forms its armature, and the carbon C is moved away from contact with the other carbon and the arc established between the points. The carbons then burn down as in the Jablochkoff candles, and are consumed at the rate of about five inches per hour. By making the support of the candle hollow, Mr. Wilde is enabled to use much longer carbons. In some instances they are twenty-six inches long, and are both slipped upward at intervals through the jaws holding them. In this way they may be made to last four or five hours without needing any renewal of carbons. When the number of hours of lighting is greater than five, a number of candles are grouped into the same lamp.

THE JAMIN CANDLE.

When the Jablochkoff candle was brought out, Jamin devoted himself exclusively to the study of improvements on it. Like many others, he deprecated the use of the kaolin, and his experiments were made with carbons separated by an air space only, as in the Wilde candle. In Jamin's opinion, one great disadvantage of the Jablochkoff candle was the projection of its light upward instead of downward, and when used in street lighting, lights the atmosphere rather than the ground. It was not expedient to invert it, as that rendered the light very unsteady. The heated gases and warmed air around the arc tend to rise, and in doing so produce air currents like those that lick the flame of a wax candle, and the arc is constantly displaced toward one side or the other, which renders it unsteady. Jamin studied various methods by which the arc could be maintained fixedly at the tips of the carbons, and finally accomplished it by taking advantage of the fact that parallel currents flowing in the same direction attract each other, and that an arc placed near another, or near a conductor carrying a current, will be attracted when the currents in both parts are flowing in the same direction, and repelled when they are flowing in contrary directions. The principle of the Jamin candle is diagrammatically represented in fig. 272. In this candle the conductor L forms a coil, or hank, around the carbons *c* c^1. The arrows show that the currents in the carbon *c* and the side 1 of the hank of wire are always in the same relative direction, and that such is also the case for c^1 and 2, as well as for *b* b^1 and *d* d^1. The current being alternate, the direction of the arrows would,

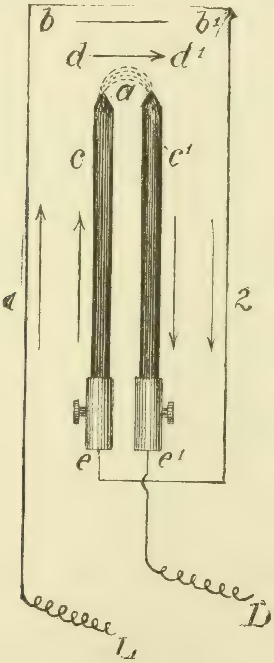

Fig. 272.

of course, be reversed during every second impulse, but the relative directions of each couple would remain the same. It follows from this condition that as long as the current passes, the carbon *c* will be attracted to the left and the carbon c^1 to the right, and the arc *a*, instead of passing in a straight line between the tips, will be pulled upward and form an arch.

Fig. 273 shows an early form of the Jamin candle. The wire is coiled into a hank, which forms the suspension brackets by which the candle proper is supported; and the ends of the wire also form the connections by means of which it is included in the circuit. In some cases the kaolin was used and the carbons were connected at the tips by the plumbago mixture which completed the circuit in the Jablochkoff candle, but later the kaolin was dispensed with, and the circuits were completed by the carbons coming into contact under the influence of a spring. The attraction caused by the current in the surrounding or directing coil was sufficient to move the carbons apart and establish the arc, which was sometimes attracted so quickly and powerfully by the magnetic reaction between it and the coil that it would become arched and break in two, thus opening the circuit.

The latest form of the Jamin candle embodies some modifications. The directing coil is in the form of a flattened hank wound in a grooved frame of thin copper, scarcely thicker than the carbons, in order that the light from the candles inside the coil may not be too much intercepted and give rise to shadows. In each burner there are three sets of carbons, but only one set is consumed at a time, and the action of transferring the current to the next set is automatic. The carbons are all held in clips on the ends of arms supported by a flat platform of slate, ebonite or other insulating material. The arm to which the left-hand carbon of each set is attached is pivoted so as to oscillate in the plane of the coil, and can therefore move the left-hand carbon into contact with the right-hand carbon, or away from it. The current passes through the regulating coil on its way to the candles, the three left-hand carbons being electrically joined together, and likewise the three right-hand carbons. At the upper portion of the regulating coil a piece of soft sheet-iron is bent over it, forming a kind of inverted U magnet, which becomes magnetic under the influence of the current passing in the coil. A flat armature pivoted at one end can move up and down in response to the power of the magnet.

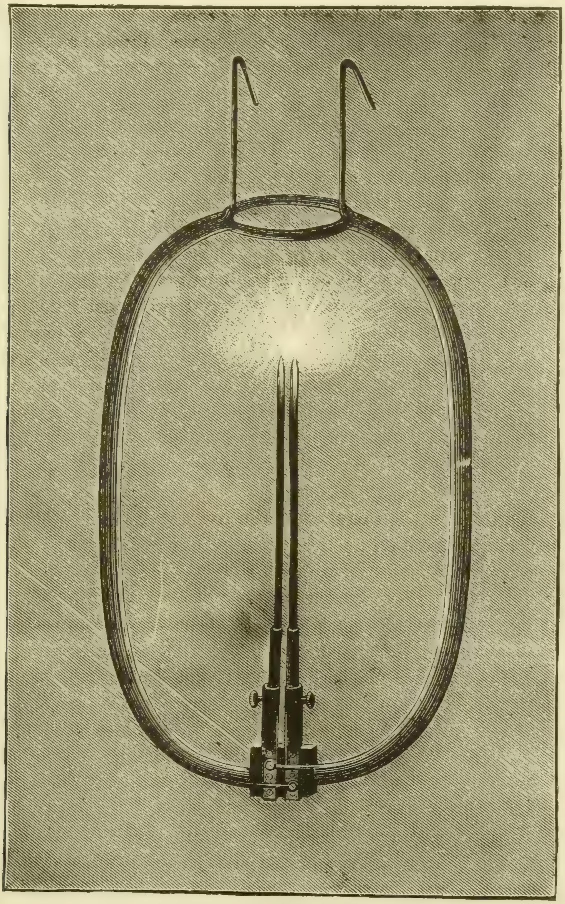

Fig. 273.

Each of the arms holding the left-hand carbons is connected with this armature and controlled by it; when the armature is not attracted it falls down by its weight, and the carbons move into contact, but when it is attracted they move apart. The right-hand carbons are held in clips on arms which can also oscillate, but not in the same plane. They tend to move at right angles to the others. A spring normally holds them out of line. In this situation the left-hand carbon would be unable to come into contact with the right-hand carbon held in this clip; but when the right-hand carbon is put in place, a small wire hook is brought around it and fastened at the other end to an arm, by which the right hand carbon is thus held in line in opposition to the spring. On passing the current, the armature is attracted, the carbons are separated and the arc is established. Now, if the carbons were all of equal length, each set would become separated at the same instant, consequently the current would be divided equally between the three sets. In practice, the sets of carbon are made of unequal length, therefore, only the longest set comes into contact, and at that set the arc is first established. When this set is almost consumed, and the candle has burned down almost to the clips holding the carbons, the small wire hook which holds the arm of the right-hand carbon in place is fused by the heat of the arc. Under the influence of the spring, the carbon holder flies out of position; and as the contact cannot be re-established between it and its mate, the armature falls down farther and the next set of carbons is brought into play. After this the action proceeds as before.

THE MÜLLER INCANDESCENT LAMP.

Mr. Müller's incandescent lamp is shown partly in section in two views in fig. 274. In this lamp the inventor secures the following important results: First, replacing the carbon filament without breaking or rendering useless any part of the lamp; second, preventing the entrance of air through the joints between the plug and the conductors passing through it to the carbon filament.

The glass globe or bulb is provided with a flaring strengthened neck, fitting very tightly on a bevelled glass stopper or plug, which is secured air-tight by means of packing material in a hollow base, D, adapted to be screwed on or otherwise attached to a bracket or chandelier arm. The glass plug and the neck of the globe are ground together so as to fit air-tight against each other. A packing is placed around the plug and the edge of the neck as shown. Two carbon conductors of suitable thickness are passed through longitudinal openings in the glass plug, projecting from the top and bottom of the plug, and secured in the plug by a suitable cement forming air-proof joints.

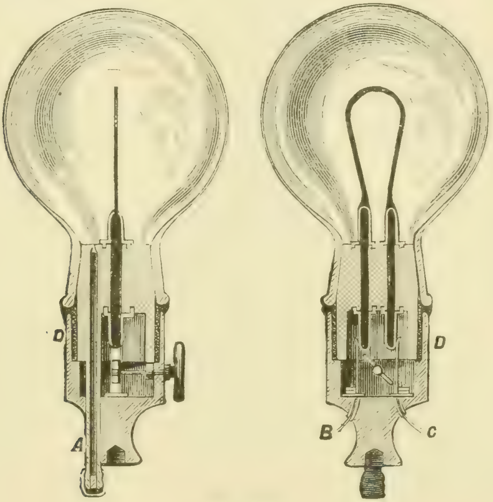

Fig. 274.

Copper rings are cast or blown into the top and bottom of the plug around the apertures through which the carbon conductors pass, and these rings project slightly from the ends of the plug. Copper is then precipitated by means of electricity around the projecting ends of the carbons and the rings. By this means the projecting ends of the carbons will be strengthened and prevented from being broken off and the joint will be made air-tight.

The upper ends of the carbons are provided with slots into which the ends of a carbon filament are passed and secured by means of a peculiar cement. A glass seal tube projects from the bottom of the plug through the base of the lamp, in which it is secured air-tight by means of cement. The end of this tube extends through the plug, and is contracted at its upper end. This tube is stopped at both ends, and the intervening space is filled with mercury.

Two insulated spring-contact strips project upward from the bottom of the recess in the lamp base, and rest against the lower projecting ends of the carbons. These strips are connected with conducting wires, B C, leading to the electric generator. A key journaled in the lamp base has at its inner end a cross piece, which is of sufficient length to separate the strips and remove them from the ends of the carbons when it is in a horizontal position. When this cross piece is in a vertical position, the strips are released and rest against the ends of the carbons.

Should the carbon filament be destroyed or broken, the globe is removed, a new filament is inserted, the globe is replaced, and the air is exhausted.

THE EDISON ARC LAMP.

The principle of the Edison arc light regulator is shown in fig. 275. M and M^1 are two electro-magnets of the same or approximately the same resistance. The former is located in the main circuit 1, 2, in which are also the carbon electrodes, C C^1, of the lamp, and the latter is located in a shunt circuit, 3, 4, which is formed around the arc or the carbon electrodes. A second shunt circuit, 5, 6, with a small resistance, R, is formed around the electro-magnet, M, this circuit being joined to the main circuit on opposite sides of the connection of M therewith. The electro-magnet M, while of the same resistance as M^1, has a greater weight of copper in its coils. M and M^1 act oppositely upon a stationary core, B. The armature, A, is carried by a lever, A^1, which works a gripping eye, *b*, for lifting the upper carbon electrode, C, to form an arc and for regulating the feed of the carbon electrode. When C and C^1 are in contact, M predominates and lifts C, so as to form the arc. When the arc increases to a definite degree, M^1 counteracts the sustaining effect of M, and C is allowed to drop until again arrested by M. The low resistance shunt circuit, 5, 6, reduces the resistance of the main line and allows the current to flow freely to the lamps. In another form of this regulator M and M^1 are solenoids, and act upon the same movable core which is connected directly with the lever that works the gripping eye.

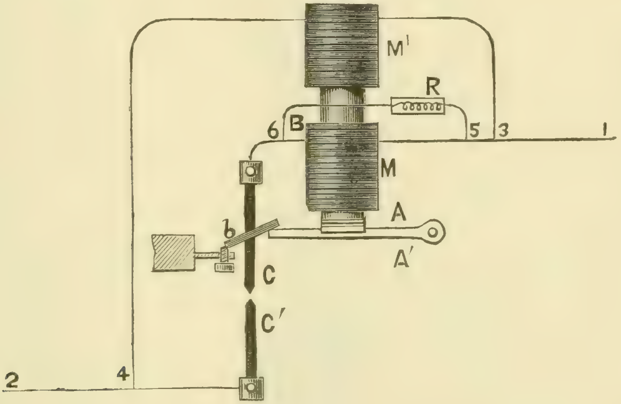

Fig. 275.

THE HOCKHAUSEN ARC LAMP.

Fig. 276 presents a general view of the Hockhausen lamp, manufactured by the Excelsior Electric Company for ordinary installations. The lower carbon is fixed, and the upper carbon feeds itself by its own weight, the motion being controlled and regulated by suitable electrical and mechanical devices. The frame of the lamp is insulated from all parts of the mechanism through which the current has to pass. The lamp may therefore be touched anywhere on the outside with absolute immunity

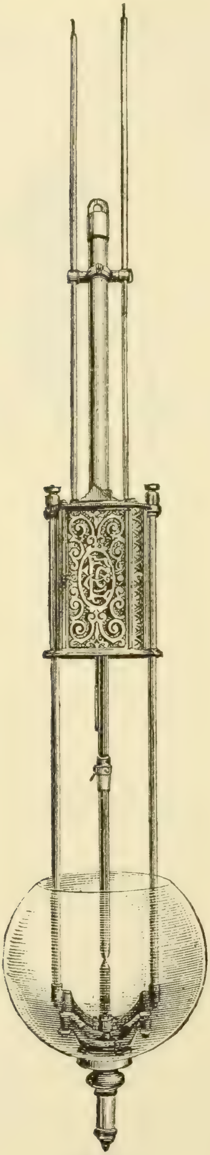

Fig. 276.

from shocks. The terminals of the lamp consist of two insulated wires issuing from the top of the regulating mechanism, from which they are insulated by vulcanite sleeves. They pass through similar sleeves in the ends of a small yoke fastened to the tube which serves to protect the carbon rod. The suspension rods which support the lower carbon and the glass globe consist of iron rods enamelled with a covering of glazed white porcelain. These suspension rods pass down close to the carbon rod in a line with the outer margins of the case of the regulating mechanism, from which they are insulated by vulcanite bushings. In arc lamps adapted to be used in series, the regulating mechanism is controlled by a differential action between two opposing forces, one of which tends to separate the carbons, and the other to bring them together. In the Hockhausen lamp there is such a differential action, but the force which tends to produce the separation is derived from a spring, and not from a magnet or solenoid included in the main circuit, as is the case in other lamps. There is a main circuit magnet in the regulator, but its office is merely to release the spring when the current is put on, by removing a weight (the armature) that holds it down.

Fig. 277 shows the regulating mechanism of the single lamp in side elevation, the side panels of the case being removed. In the upper portion of the case is a flat piece of vulcanite, *v*, to which are fastened two pieces of brass, *a a*, which serve to make the connections between the terminal wires P N, and other portions of the lamp circuit. The right hand piece receives the current from the positive terminal wire P. The carbon rod R passes down through a hole in this piece, and thus forms contact with it and receives current. It also receives current through a brass comb brush B, connected with piece *a*. At the bottom of the case the carbon rod passes through a piece of brass, also resting on vulcanite insulation *z*. From this piece of brass, which is thus directly connected to the positive terminal, there is a wire passing up and leading to the fine wire solenoids D, as shown in the figure. The brass spring *p*, which forms part of the switch, is also attached to this brass piece. The current, after passing through the arc, returns upward by the right hand suspension rod as far as K, where it enters through a wire leading to a coupling, 3. From this coupling there is a branch which goes to the main circuit solenoids M, from which a wire, *b*, leads to the left hand piece *a*, and consequently to the negative terminal wire N. The brass piece *t* is connected with a brass post on the further side of the lamp and the upper end of which is seen at *r*. This brass post is connected with the negative terminal by a wire seen passing up close to the left side of the carbon rod. To this wire is connected the other end of the solenoids D, which forms a derived circuit around the arc. The piece *t* is connected to the circuit on the negative side of the arc, while the spring *p* is connected on the positive side. Hence, by pressing the spring into contact with *t* the lamp becomes short-circuited. This arrangement, therefore, furnishes a simple switch. The spring is pushed into contact by an arm of vulcanite, *o*, which is swung round by a lever or key, conveniently disposed below the case.

The feed mechanism is quite simple. The carbon rod is provided with a rack which gears into a small pinion. This pinion is not shown in the figure, for it is on the same shaft as the toothed wheel W, and therefore hidden by the latter. The pinion is insulated from the shaft and from the wheel W, however. It is fitted on a vulcanite sleeve, and held in position by being fastened to a vulcanite disk on the wheel W. By this insulation the current passing through the carbon rod is prevented access to the mechanism and to the case. On this side of the escapement wheel *m* is a ratchet wheel, not shown in the engraving. This ratchet wheel is fastened to a sleeve on the shaft of the wheel *m*, together with a pinion gearing with the wheel W. The teeth of the ratchet wheel are so directed that when the carbon rod is moved upward it slips on the shaft of the wheel *m*; but when the carbon rod descends it engages the escapement wheel *m*, which operates the escapement *x* fastened on a common shaft with a long fan partly shown in white near *h*. The little white dot above the escapement shows a pin that controls or checks the movement.

The framework *f f* of the escapement mechanism is itself pivoted at *k*, and can be swung bodily from right to left. The U-shaped armature of the solenoids D is attached to the left end of this framework, and moves up and down at the same time. The spring S normally tends to lift the left side of the framework, or, in other words, to make it swing from left to right. As long as no current is passing through the coils M, however, the weight of the armature *g* counteracts this spring and holds down the left end of framework *f*. In this situation the escapement *x* is freed from the escapement wheel *m* by the lever *l*, which is tilted upward and moves the escapement shaft to the right. The object of this release of the escapement wheel *m* is to allow the carbon rod R to move down the moment the current is cut off from the lamp, so as to close the circuit through the carbons again.

When the current is sent through the lamp it passes through the carbon circuit, including the solenoids M, and also in smaller proportion through the fine wire solenoids D in derived circuit. The two vertical cores of the armature *g* are sucked up into the solenoids M, and the weight counteracting the spring S is released. The framework *f* is thereby moved, and as soon as it begins to move, the lever *l* tilts back again, causing the escapement *x* to engage the wheel *m* once more. The further motion of the framework causes the carbon rod to be raised bodily, so as to cause separation between the carbons and establish the arc. But as the weight of the carbon rod would move the train of wheels and cause the escapement *x* with its attached fan to beat to and fro, the carbons would soon touch again. This is prevented by a weighted lever *d*, which catches the lower end of the fan and stops its motion. As the framework *f* is moved under the influence of the spring S, the pivot of this lever moves toward the left. This has the same effect as if the regulating screw *c* were moved out of its way to the right. The hooked portion consequently tips upward and engages the lower end of the fan.

As long as current passes through the lamp, the cores *g* remain attracted by the solenoids M. The framework does not necessarily move to this extent, however, because the spring S is now opposed by the solenoids D, and as the current diverted through the latter increases directly with the length of the arc, a point

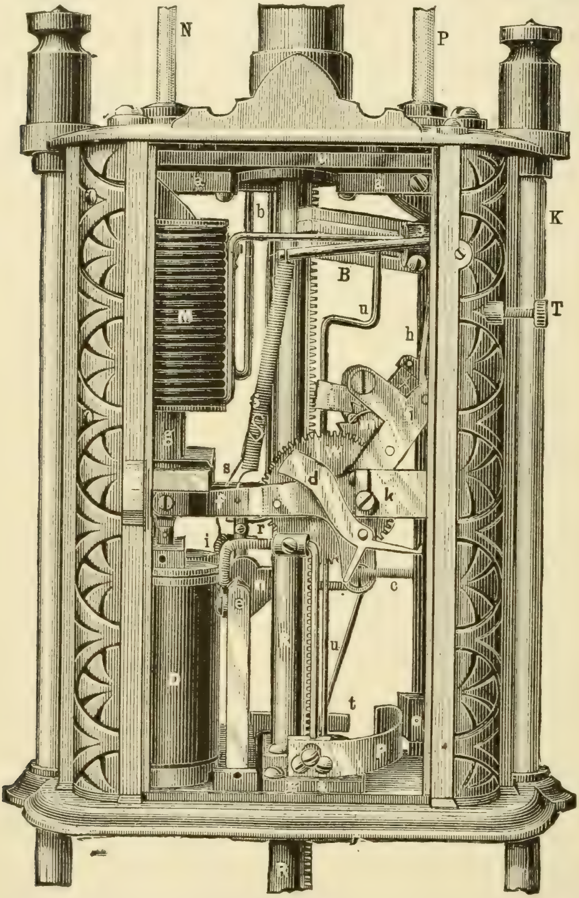

Fig. 277.

of equilibrium is reached where the spring is balanced by the attraction of the solenoids D. As the carbon consumes the arc lengthens, and this leads to an increased diversion of current through D, which overpowers the spring S and pulls down the framework. This has the effect of moving the lever *d* against the screw *c*, so as to release the escapement fan, which begins to vibrate. After a few teeth of the wheel *m* have escaped, perhaps, the arc has regained its normal length, and as the shunt solenoids D have thereby become weakened, the spring S is released, so that the framework again moves upward. If the spring S has its tension increased, then the arc will be longer, because it will require a greater diversion of current through the shunt D to overcome this tension. The tension of this spring may be readily adjusted by means of a screw T, which is shown on the outside of the case. The differential action is produced between the spring S and solenoids D; the main circuit solenoids M serving only to release this spring.

Mr. Hockhausen has added an automatic cut-out to this lamp, to provide for its extinguishment in case it fails to feed from any cause. Behind the vertical post *e* is a supplementary armature, which is acted upon by undue increase of current in the solenoids D when the arc becomes too long. It consists of a flat piece of sheet iron pivoted at the top between two brass posts, one of which (*r*) is connected by wire with the negative terminal N. Under the influence of the current in D, this armature is tilted to the left, and when the arc acquires an abnormal length, the attraction proceeds until the armature touches a contact piece connected by wire *u u* to the coupling 3. By this means it will be seen that the solenoids M are short circuited. The tilting motion of the armature has placed a flat spring, *s*, in such a position that when the core *g* falls down, being no longer attracted, it presses this flat spring against a contact connected with the positive pole, thus short circuiting the lamp.

The same mechanism is also depended upon to short-circuit the lamp when the carbons are consumed. For this purpose the carbon rod is provided with a small spring projecting from its surface at the upper end. When the carbon rod has descended sufficiently, this engages against a piece of vulcanite, *n*, attached to the supplementary armature, and causes the armature to tilt, with the effect of short circuiting the lamp in the same way as before. The regulating mechanism of the double lamp (fig. 278) embodies the same principles of construction. The main difference is that in this case there are two escapement

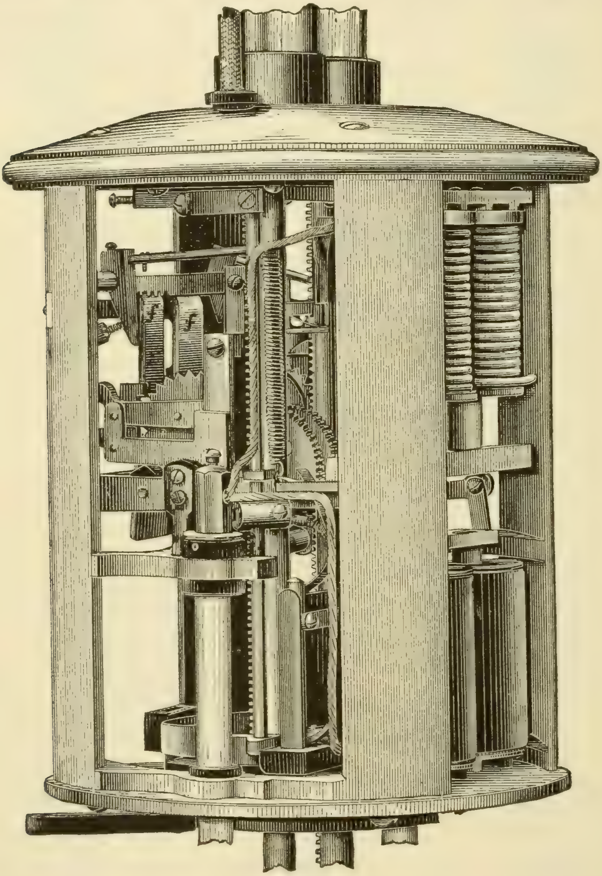

Fig. 278.

mechanisms, both carried by the same framework, one for each carbon rod. The escapements and fans (*f f*) are engaged and released in both at the same time, but there is always one carbon rod which is prevented from descending. The device by which this is accomplished is shown in Fig. 279. The left hand carbon rod A is prevented from descending by a pin, *a*, resting against the end of a bell crank lever *e d*, which is held forcibly against it by a spring, S. The other carbon rod, B, however, is free to descend. The arc is therefore produced on this side, the other carbon being held at a slight distance, out of contact. When the carbon rod B has descended quite down, a little pin, *b*, comes against the other end of the crank lever and moves this lever into a position represented by the dotted lines, thus allowing carbon rod A to slip down. The carbons on this side (A) now come in contact, and the arc at B dies out. The regulator now causes the separation between this new set of carbons, the carbon rod B remaining suspended by the pin *b*. The switch and the automatic cut-out just described are used in this lamp. In this case the second carbon rod (A) is provided with a pin at the upper end so as to tilt the armature of the cut-out and short circuit the lamp when the second set of carbons is consumed.

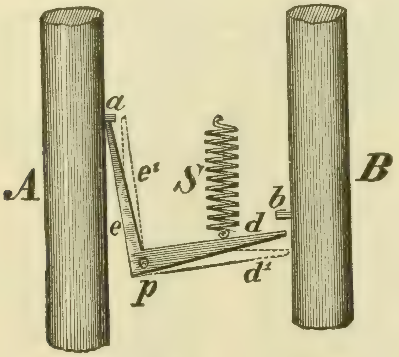

Fig. 279.

These lamps appear to regulate their arc with great nicety and precision. Clockwork mechanism for arc lamps is neces-

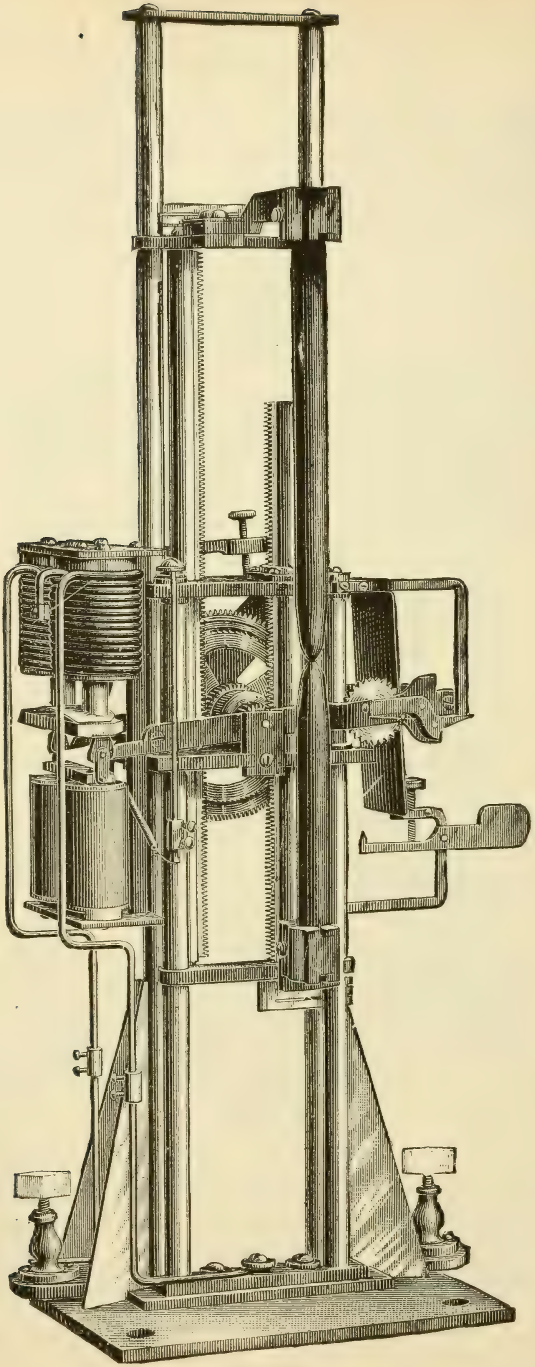

Fig. 280.

sarily more complicated than clutch mechanisms, but there is no undue complication in this case, considering the variety of functions to be performed. The arc maintained is about an eighth of an inch long, and the carbons used are seven-sixteenths of an inch in diameter, and with the current of ten ampères usually maintained in circuit, the crater in the positive carbon is well defined and clean.

Fig. 280 shows a focusing regulator for steamboat search lights, locomotive headlights, or other purposes where the arc light is used, with a parabolic reflector for projecting a beam of light in one direction. In regulators of this description the same mechanism has to control the two carbons, and make the lower one feed upward and the upward one feed downward, so that the arc may always remain in the focus of the reflector. In this case this result is attained by an easy modification of the regulating mechanism of the standard arc lamp. The carbon rods both have racks, and they gear into pinions carried on the same sleeve, though insulated from each other.

They are placed on opposite sides of the shaft, and therefore the downward motion of the positive carbon rod causes the upward motion of the negative carbon rod. The upper carbon consumes twice as rapidly as the lower, and for that reason the pinion of its carbon rod is of a diameter twice as large, in order that it may feed down twice as fast as the lower one feeds up. These pinions are fastened to a ratchet wheel which slips on the shaft of the large toothed wheel when the carbons are moved apart, but engages this wheel when the carbons are released. This toothed wheel gears into the pinion of a shaft carrying the escapement wheel. When no current is passing through the lamp the weight of the cores of the upper solenoids tilt the framework of the mechanism as in the standard lamp, and in this situation also the escapement is freed by a small lever. When the current is passed through the lamp the framework is tilted in the other direction by the spring, and the escapement is again engaged. The lower end of the fan is also moved down by this tilting movement until it is impeded and stopped by a small hooked lever shown in the figure. The operation of this regulator is therefore the same as in the standard lamp. The carbon clamp of each carbon rod is attached to a transverse piece sliding on two vertical posts, and fastened to the rod. In this way the carbons may be placed at a distance from the body of the regulator, thus leaving room for placing a reflector behind the carbons.

THE HOCKHAUSEN INCANDESCENT LAMP.

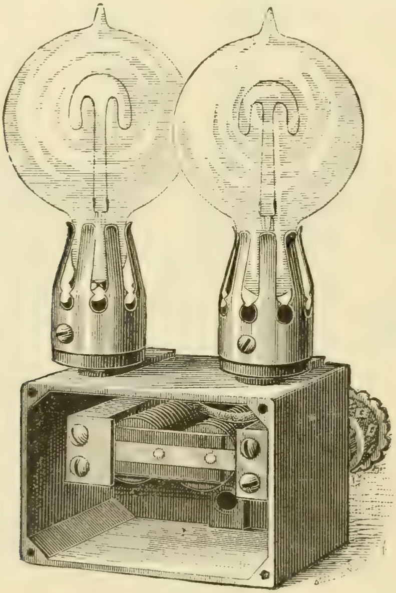

Fig. 281.

This lamp (Fig. 281) differs from others in the form given to the carbon loop, which, in this case, assumes the semblance of a letter T. The carbon loop is formed of vegetable fibre of a peculiar kind, which is found very durable. The weak spot in incandescent lamps is generally in the imperfect connection between the wires passing through the glass and the carbon filament. It is claimed that in these lamps the connections are made in an improved manner, which leaves nothing to be desired.

Fig. 282 shows a plain form of holder used with these lamps. The three bent wire springs embrace the lower portion or neck of the lamp, and the small platinum wires protruding through glass are pinched between the split extremities of the circuit, connecting by means of screws, one on each side. Fig. 283 shows one of these holders mounted on a hand stand and supporting an incandescent lamp. Fig. 284 shows a more ornamental form of holder, in which the bent wire springs are replaced by sheet brass springs, forming part of the casing.

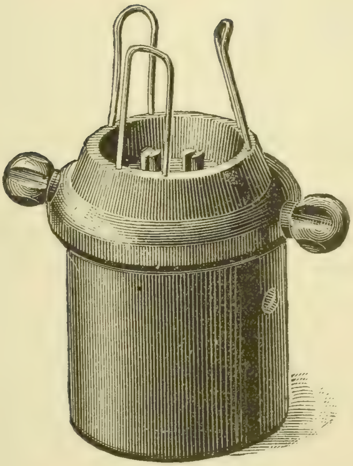

Fig. 282.

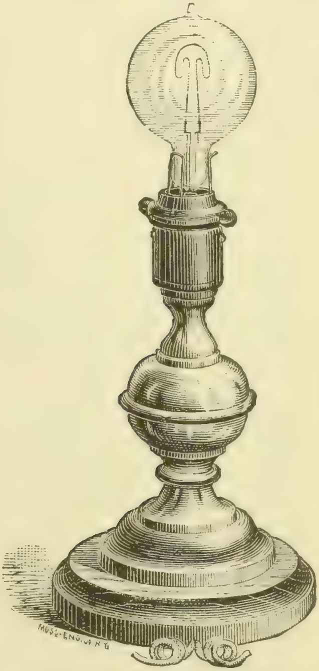
MOSS-ENG.Co N.Y.

Fig. 283.

The device represented in fig. 281 is called an automatic substituter. The circuit is divided at first into two branches, one of which includes the electro-magnet shown in the base, together with one of the lamps. The other includes the other lamp, but remains closed only as long as the armature is retracted. When the current is put on, therefore, and the magnet is excited, the second circuit is opened and only the first lamp remains in circuit. If this lamp breaks, however, the armature instantly falls back and closes the circuit through the second lamp. There are many situations where it would be very desirable to use the incandescent light in connection with the arc light; and many places where a few incandescent lights would be more convenient and useful than one arc light. To meet this want, attempts have been made to run incandescent lights in the same circuit with arc lights. It seems quite plausible that if the current in circuit is ten ampères, and each incandescent lamp requires a current of one ampère, that by dividing the circuit into ten branches, each of which includes a light, the lamps ought to burn successfully. But the trouble is, that if one lamp breaks the other nine will receive the ten ampères among them, or each will receive one-tenth of an ampère more than is required. This may lead to the rupture of another, and this again cause an increase of one-tenth of an ampère. In short, the breaking of one lamp endangers the rest. Mr. Hockhausen proposes to remedy the difficulty when a lamp breaks by shunting the surplus current through an equivalent resistance. If two lamps break he diminishes this resistance. Finally, if there is danger that the lamps may burn up altogether, they are all cut out of the circuit by means of the apparatus shown in fig. 285. The switch shown on the right hand side is normally pulled toward the cover by a spring not shown in the figure. In this condition the incandescent lamps are cut out of the arc light circuit. The contact piece nearer to the cover of the case is connected to the armature of an electro-magnet within. This electro-magnet is included in the main circuit, and when the current is passing, it attracts its armature, and causes the contact piece outside the case to project out from the surface of the case. If, now, the switch is moved to the right, it is prevented from moving back by the insulated end of this protruding contact. In this condition, the incandescent lamps are included in the circuit—that is to say, the circuit divides at one point into several branches, in which are included the lamps—one in each branch. But there is one of these branches which, instead of a lamp, includes a relay magnet of rather high resistance. Now, if a lamp breaks, the current increases in all the remaining branches.

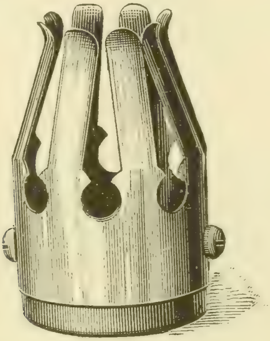

Fig. 284.

The relay feels this increase, and its armature comes against a contact which closes the circuit through another branch, including an equivalent resistance placed in the case, and consisting of wire wound on wooden reels, every turn of the wire being accessible to the air so as to admit of ready cooling. If another lamp breaks, the armature of the relay is attracted further, and closes a circuit through a lamp placed on top of the regulator case to warn the attendant, who immediately proceeds to replace the two broken lamps. But meanwhile another lamp still may break, and as the relay cannot make further compensation, there is imminent danger that the other lamps will break. This is prevented by a kind of automatic cut out. The relay is provided with a supplementary armature, which is attracted when the current increases beyond the limit compensated for by the relay itself. The motion of this armature short circuits the electro-magnet in the main circuit, whose function is to make the contact piece protrude on the outside of the case. Instantly this contact piece moves back close to the surface of the case again, and the switch is quickly pulled back by its spring. As soon as it again touches the metallic surface of this contact the incandescent lamps are short circuited, and the arc lights are left alone in the circuit. It is evident that the principle of this regulator may be extended not only to one, but to several multiple series, and the number of lamps compensated for may be regulated quite easily. The objection to this mode of regulation is, that there is no economy of energy when only a few of the lights are burning,

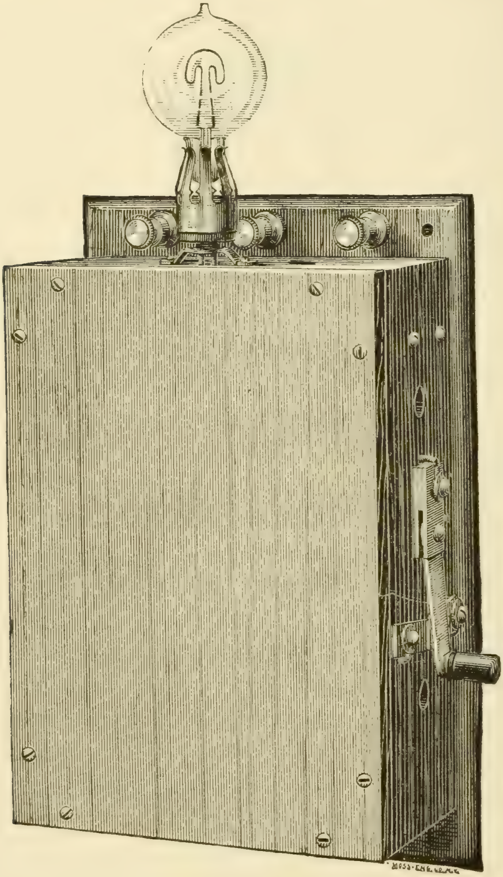

Fig. 285.

because the compensating branches absorb the energy previously expended in the lamp in producing light. However, as the number of lights accidentally put out would usually represent only a trifling proportion of the total in use, this objection is not serious. Besides, in cases where this procedure is resorted to, expediency or convenience is generally a more important consideration than economy.

THE WESTON ARC LAMP.

In 1873 Edward Weston, who was at that time engaged in the business of nickel plating in New York City, and who employed dynamo-electric machines in carrying on his business, constructed a machine from his own designs, which embodied various improvements over other machines of this class at that time in the market, and among other experiments which he conducted with this machine, were some in electric arc lighting. Mr. Weston continued from that time forward to build dynamo-machines in greater or less numbers for sale, introducing from time to time many important improvements, but his labors in this connection will be more particularly referred to in another part of this work.

The arc-lighting apparatus used in Weston's early experiments was of a temporary character, the carbons being mounted in clamps in a frame and adjusted by hand, which served the purpose well enough, as the object of the experiments at that time was more particularly to determine the capacity of the dynamo-machines for this service. It is worthy of remark, however, that even in these early experiments in 1873 Weston made use of electro-plated copper-coated carbons, the employment of which has now become universal.

The practical advantages possessed by the dynamo-machines of Mr. Weston in electro-plating and other industrial applications, soon began to attract attention, and the commercial demand for them increased to such an extent that, in 1875, he removed to Newark, New Jersey, and commenced the manufacture of the machines, a business which he carried on until

1877, when a corporation was organized, under the name of the Weston Dynamo-Electric Machine Company, for continuing the business. During the years 1875 and 1876 Mr. Weston experimented almost continuously with electric-arc lamps, and constructed a number of different forms, most of which were essentially modifications of typical forms well known at that date. Electro-plated carbons were employed in many of these experiments and continuously after the spring of 1876.

The Centennial Exhibition in Philadelphia, in 1876, served to direct the attention of electricians largely to the development of arc systems of lighting, and in consequence of this, during the latter part of 1876 and the early part of 1877, Weston built a number of dynamo-machines especially adapted for lighting purposes. While thus engaged, his attention became directed to the improvement of the arc-lamp, which up to that time had not successfully been operated when more than one was included in the same circuit. Early in 1877 he commenced a course of experiments in operating a number of lights in series. An examination of the conditions of the problem showed that in order to accomplish this successfully it was necessary to increase the electro-motive force of the current in proportion to the number of lamps in circuit, and this in turn rendered it desirable that the length and consequent resistance of each arc should be reduced as far as possible, and the cross-section of the carbons also diminished. It was also perceived to be essential that the different arcs should be as uniform as possible. In Weston's first experiments, he attempted to maintain the arc of each lamp at a fixed length by mechanical means, but after protracted experimentation, the difficulties attending this mode of regulation were found to be practically insuperable, and he accordingly turned his attention to the more promising method of automatic regulation by the force of the lighting current itself. Experiments made in this direction were much more successful. It was found that lamps properly adjusted would burn with great uniformity for a time, until some one carbon was automatically fed forward, when the sudden increase in the strength of current arising therefrom would give rise to disturbances in the other lamps, and these in turn would react upon the circuit, so that all the lamps were rendered unsteady and flickering, and in some cases entirely extinguished. It therefore became a desideratum to devise some means of readjusting all the lamps simultaneously at stated intervals, by liberating all the movable carbons in the different lamps to the uncontrolled action of gravity or other constant force. An apparatus was designed, by which a mechanical rheotome, at stated intervals, suddenly introduced into the lamp circuit, for a moment only, a resistance sufficient to weaken the current, and cause all the lamps to simultaneously drop their carbons to the initial point, when they were immediately readjusted by the normal action of their respective regulating magnets.

The first series of lamps, five in number, embodying the above described principles of regulation, was put in operation in 1878, and was for a time employed for lighting a manufacturing establishment in Newark. This organization, although quite satisfactory so far as the performance of the lamps themselves was concerned, was open to very serious objection in a commercial sense, on the score of unnecessary waste of energy. In consequence of the varying load or mechanical resistance, and the suddenness of the changes, the strain on the dynamo machine and its driving engine was very severe. It should be mentioned that the differential principle of regulation by means of a magnet placed in a shunt spanning the arc, which is now in almost universal use in arc-lighting systems, was employed in this application, and in fact lamps embodying this principle were in actual practical operation in Weston's factory as early as September or October, 1877.

Another method of regulation was tried in 1878, which consisted simply of a permanent shunt around the arc, in which shunt a resistance was inserted. This was tried in actual service, and a series of four lamps was operated for some time with very fair results, but inasmuch as the entire current which passed through the shunt was diverted from the arc, no inconsiderable

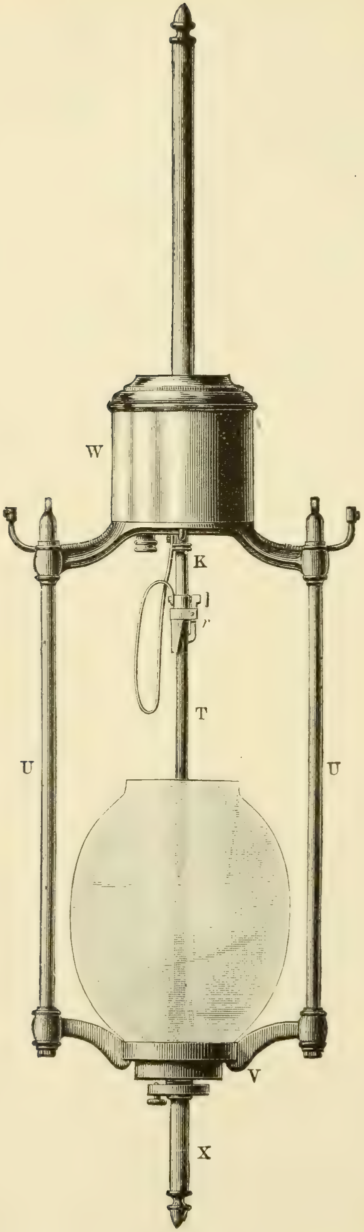

Fig. 286.

portion of the total energy was actually wasted, so far as its illuminating effects were concerned, and hence the results were far from economical.

The next improvement made by Mr. Weston was during the year 1879, and consisted of an organization in which an independent regulating magnet was placed in a shunt circuit spanning the arc.

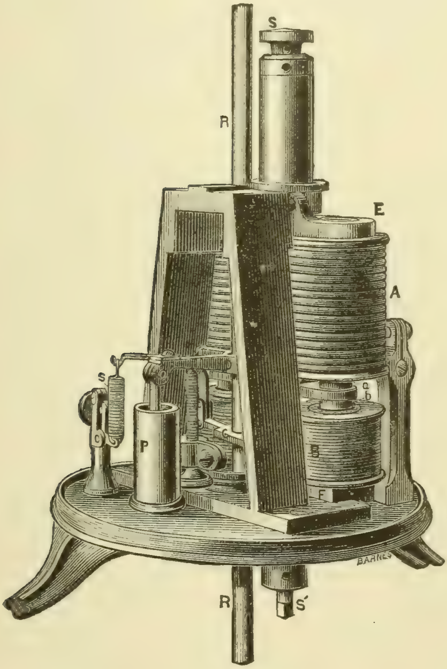

Fig. 287.

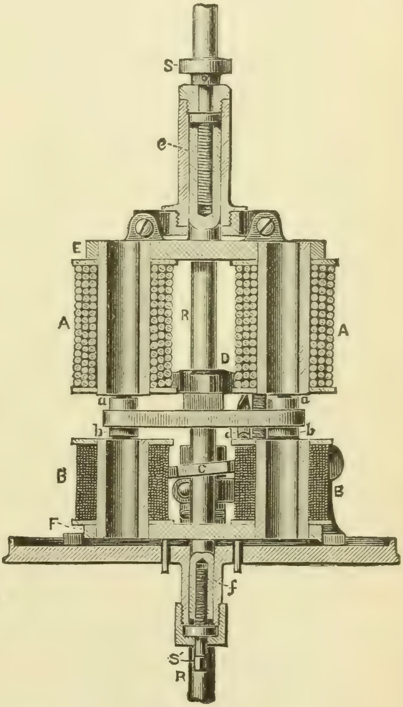

Fig. 288.

Figure 286 shows the external appearance of this lamp when mounted and ready for use. The regulating mechanism is placed within a hollow metallic cylinder W, from the bottom of which depend two metallic rods U U. A base, V, is attached to these, supporting the lower carbon holder X and the glass globe which incloses the arc. The movable upper carbon or electrode, T, is secured to its carbon-holder, K, by means of a clamp, *r*, to which the electric current is brought by a flexible conductor, as shown in the figure. In this, as in most other lamps of modern construction, the lower carbon is stationary, while the upper one is fed downward by means of the regulating mechanism as fast as consumption takes place. The regulating mechanism contained within the cylindrical case W, is shown in perspective in figure 287, and in vertical transverse section in figure 288. A is the electro-magnet which supports and moves the upper carbon electrode. Its coils are composed of a comparatively few convolutions of thick wire. This magnet is included in the main circuit which passes through the carbons and the arc. B B is a second electro-magnet, the coils of which are composed of a large number of convolutions of thin wire. This magnet is placed in a shunt circuit spanning the arc, and the two are arranged to act in opposite directions, or differentially, upon a common armature.

The electro-magnets and their common armature are in this lamp of a peculiar construction, which is designed to combine the advantages of the axial magnet or solenoid with those of the ordinary electro-magnet, and, at the same time, to avoid the inconveniences of each. The advantage of the solenoid over the ordinary electro-magnet consists in the greater range of movement which it is possible to give the moving core or armature under the influence of electric currents of given strength. Its disadvantage consists in the fact that a much larger coil and a correspondingly greater consumption of electrical energy is required to produce a given mechanical effect. The converse of this is true of ordinary electro-magnet and armature, in which a given mechanical force is produced by a more moderate expenditure of electrical energy, but at the same time the effective range of movement of the armature is comparatively small. In an electric arc lamp it is desirable that the magnetic force, acting in a direction opposite to that of gravity, should be as nearly as possible uniform throughout the entire range of the movement of the upper carbon electrode, and this condition is more nearly fulfilled by the use of solenoid than by the use of the ordinary electro-magnet and armature. In this lamp the cores of the electro-magnet are tubular, as shown in figure 288, and cylindrical projections of soft iron, *a a* and *b b*, are attached to the armature, which enter into the central opening of the tubular cores, but without touching them. The result produced by this organization is that the intensity of the magnetic field increases very slowly as the armature moves toward the poles of the magnet; and in consequence of the armature being thus moved through a nearly uniform field, the attractive force increases; but comparatively little in proportion to the distance which the armature moves; the effect being substantially the same as if the armature of an electro-magnet were made to approach its poles at a very oblique angle. This organization acts upon a principle essentially different from that of the solenoid, inasmuch as the movable armature when it commences to move toward the tubular core is wholly without the coil, while in the case of the solenoid the core occupies more than one-half of the length of the opening within the coil when in its normal position of rest. The action of the electro-magnet and armature are the same as in the ordinary construction, except that the magnetic force increases at a less rapid rate as the armature advances. Hence two important practical advantages are gained by the employment of this organization instead of the solenoid and core. First, the coil is very much smaller and offers much less resistance to the current, thereby effecting a material economy in the consumption of electric energy, and the weight or inertia of the armature is far less than that of the solenoid core, by reason of which its movements are more easily controlled. Second, the field through which the armature moves is more uniform than that through which the core of the solenoid moves; and hence in the operation of the lamp the equilibrium between gravity and the antagonistic magnetic force is more easily maintained.

The main electro-magnet A A is provided with an adjusting nut S, and screw *e*, by which its distance from the armature may be regulated, and the magnet B B is provided with a similar device, S′, for the same purpose. The intermediate armature, which is common to both magnets, is attached to a lever, D, seen in figure 287, which lever is pivoted behind the magnet, and is connected by a jointed link to the clutch C, which grasps the carbon holder or rod R. P is a dash-pot, consisting of a cylinder filled with glycerine, having a piston moving loosely within it, which piston is also jointed to the lever D. This device serves to prevent sudden motions of the carbon. A tension-regulating spring *s* is attached to the same lever. The operation of the regulating apparatus of this lamp is as follows: When no current is passing through the lamp, the upper carbon rests directly upon the lower one, but when a sufficiently powerful current is sent through the carbons, it traverses also the electro-magnet A A, whereupon the armature is raised, causing the clutch C to grasp the rod R and lift it, thus separating the carbons and establishing the arc. The resistance now interposed by the arc causes a portion of the current to traverse the electro-magnet B B, which, as we have before explained, is placed in a shunt circuit spanning the arc. It results from this, that the longer the arc and the greater its resistance, the stronger is the attraction of the electro-magnet B, in the shunt circuit, and the weaker is that of the electro-magnet A, in the main or arc circuit. It follows, therefore, that as the arc lengthens by the burning away of the carbons, the attraction of the former at length overpowers that of the latter, and the armature descends, releasing the clutch C from the carbon-holder and allowing the upper carbon to fall by the action of gravity until the arc is shortened sufficiently to cause the attraction of the upper electro-magnet A to again preponderate, when the first described operation is again repeated. Thus when the lamp is in operation the upper carbon is at all times delicately balanced between two opposing forces and is fed forward by an almost imperceptible intermittent advance movement, recurring at frequent and tolerably regular intervals.

A very large number of the above described lamps were made by the Weston Dynamo-Electric Machine Company, and put in commercial use in various parts of the country. It may be said that in principle this lamp is everything that could be desired. A practical objection to its extended use was found in the great accuracy of workmanship required to insure its proper performance. Even at that comparatively recent date the manufacturing facilities for this class of work were not by any means so complete as they have since become, and it was largely in consequence of these difficulties of manufacture that Mr. Weston was led to devise a new and more simple, and perhaps more practical form, which was first put on the market in 1880. In respect to its principle of operation, and its practical performance, other things being equal, the new lamp presents no special advantage over the old one ; but the simplicity of its design and the ease with which its mechanism may be constructed with interchangeable parts, has led to its very extensive use.

The mechanism of this lamp is so arranged that it fits into the same frame as the one previously described, and therefore figure 286 will serve equally well to represent its external appearance. In many cases it is desirable, as for instance in lighting public streets, squares, railway stations, and the like, that the lamps should be capable of burning continuously 15 or 16 hours. In this case a construction termed the duplex lamp is employed, which comprises two independent sets of carbons and carbon-holders, the second set of carbons being automatically brought into action after the first set has been consumed. The same controlling and regulating mechanism serves for both carbons. Figure 289 shows the external appearance of the duplex lamp, while in figure 290 the same lamp is shown, mounted upon an iron post and fitted with a hood and reflector, as used in lighting streets and public places generally. The internal mechanism of the duplex lamp is substantially the same as that of the single lamp, with the addition of certain devices for shifting the action of the regulator from one carbon-holder to the other, when necessary, and hence it will be more convenient to describe this lamp in its duplex form in connection with the shifting mechanism. Figures 291 and 292 are views in elevation of the regulating mechanism of the duplex lamp taken from opposite sides, and figure 293 is a plan view of the same.

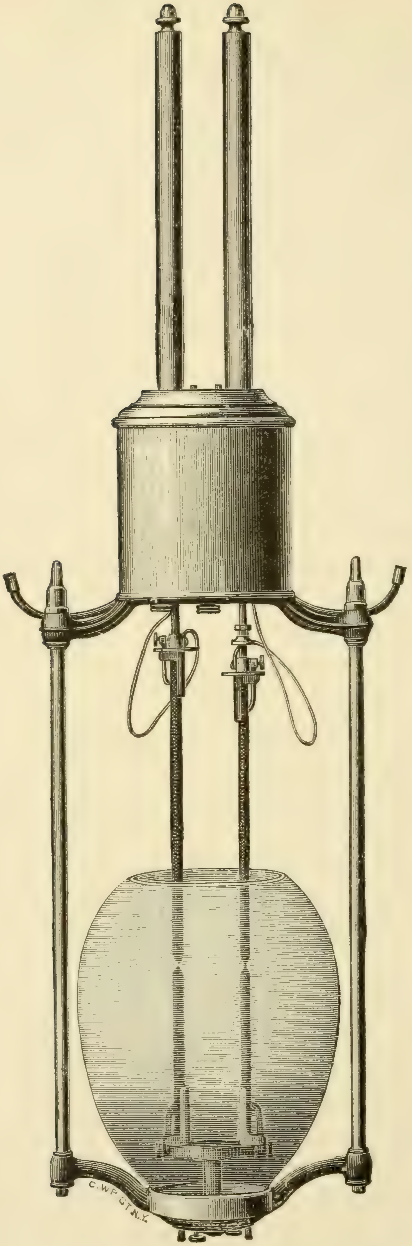

Fig. 289.

Referring to the figures, D D represents the exterior of the cylindrical coils of the electro-magnet, which is mounted upon the frame A in such a position that the centre of its upper pole, which, for convenient explanation, we will assume to be the north pole, is situated in the same vertical plane with the axis of the south pole directly beneath it.

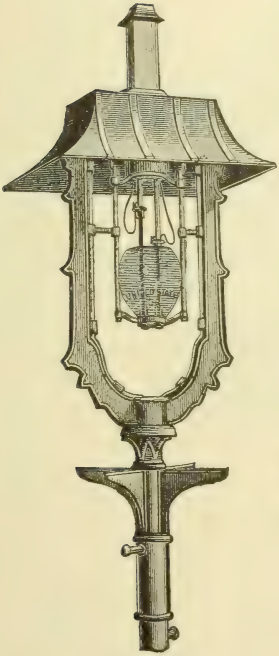

Fig. 290.

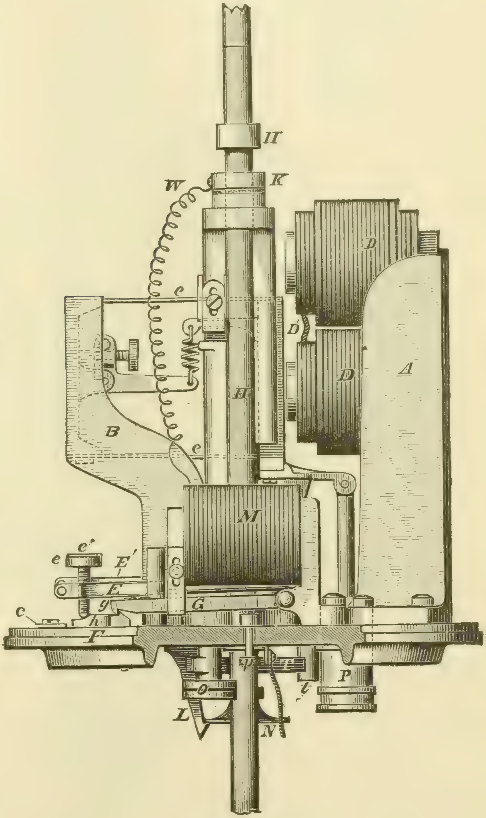

Fig. 291.

The armature D′ is of rectangular cross-section, its breadth being the same, or nearly the same, as the diameter of the poles of the electro-magnet, while its length is equal to the distance between the centres of the poles, plus twice their radius. The armature D′ is supported longitudinally in a vertical plane parallel to a plane passing through the faces of the poles, and very near to, but not touching them. The normal position is shown

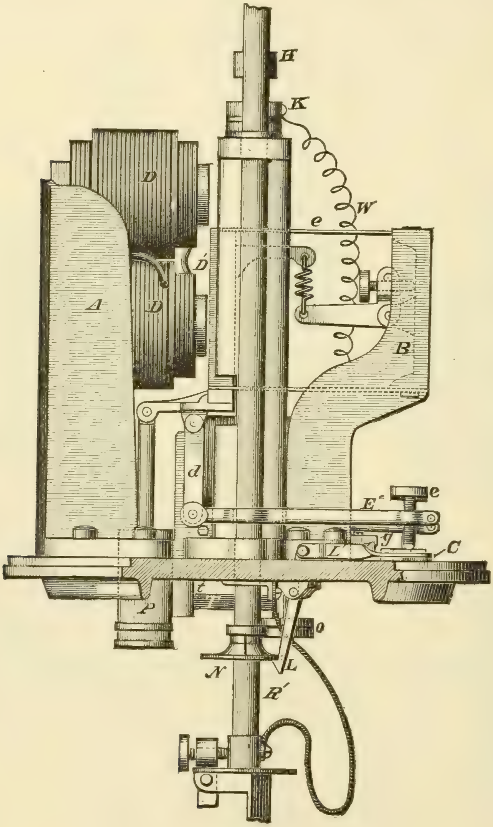

Fig. 292.

in the drawings, its lower end being a considerable distance below the south or lower pole of the electro-magnet D D, while its upper end is very nearly in the same horizontal plane with the lowest point of the periphery of the north or upper pole. The armature D′ is supported by two flexible bars, straps or springs *e e*, one of which is secured to the top and the other to the bottom thereof, while the opposite ends of the same are fixed to a stationary bracket or support B upon the frame A. The action of this electro-magnet upon its armature is as follows: When an electric current traverses the helices or coils D D, the soft iron within them becomes a magnet, the armature D at the same time becomes magnetic mainly by the inductive action of the lowermost or south pole, and owing to the position of the south pole with reference to it, it being nearly opposite the middle of the length of the armature, the latter becomes a magnet having three poles, viz.: a south pole at each end, and a north pole at or near its middle. Inasmuch as by the law of magnetic action unlike poles attract each other, the upper pole of the armature is drawn toward the upper pole of the electro-magnet. This force is exerted in a direction

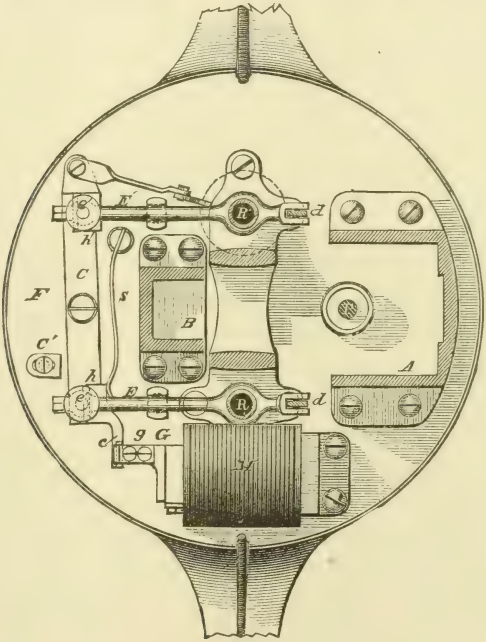

Fig. 293.

parallel to a line drawn from the poles of the magnet to the pole of the armature; that is to say, in a direction more nearly parallel to a line joining the poles of the magnet than to a line perpendicular thereto. The flexible bars or springs, *e e*, permit the armature D′ to move freely in the direction of its length within the limits of distance necessary for the operation of the lamp, while at the same time they prevent it from approaching more nearly to the poles of the magnet. Thus the armature is free to respond to the action of the vertical component of the magnetic force, but not to that of its horizontal component. Hence the resultant motion is nearly parallel to a line joining the poles of the electro-magnet, although it is in fact an arc of a circle, the centre of which is approximately coincident with the point of attachment of the flexible bar *e* to the frame at B. The manner in which the armature is mounted upon the springs *e e* with reference to the vertical position of the electro-magnet, has the effect of causing a gradual increase in the horizontal distance between the respective poles of the armature and the magnet in the ratio of the diminution of the vertical distance between them as the armature moves, and hence this manner of mounting the armature and controlling its movement with reference to the electro-magnet causes the action of the latter upon the former to be very nearly uniform throughout a considerable range of movement.

When the lamp is in operation, the movable upper carbon is acted upon simultaneously by two antagonistic forces, viz.: gravity, tending to pull it down, and thus bring it nearer the lower carbon, and magnetism, tending to draw it up, and thus separate it from the lower carbon. The theory of the operation is this: When the arc is at its normal length, the two opposing forces are in equilibrium and the movable carbon remains at rest. When the carbons burn away the length and resistance of the arc is increased, the magnetic force is correspondingly diminished, gravity preponderates and the carbon descends. When the arc is too short, or when the carbons are in contact, as at the first starting of the lamp, magnetism preponderates, and the carbon ascends. Inasmuch as gravity is constantly exerting a uniform force upon the carbon throughout the entire range of its movement, it is apparent that the adjustment will be more easily effected if the antagonistic force is also constant throughout the entire range of movement of the carbon. The mechanism by which motion is communicated from the armature to the carbon-holder is substantially the same in this lamp as in the one previously described. The same mechanism is employed for controlling the feeding of both sets of carbons. It comprises an electro-magnet, D D, differentially wound with two helices, one of thick wire, and few convolutions included in the arc circuit, and the other of thin wire and many convolutions in a derived circuit or shunt, having a comparatively high resistance, so as to adapt the lamp for use in series. A link, *d*, connects the armature D′ with the lever E′, in which an eye is formed just large enough to permit the carbon-holder R′ to slide freely through when it is precisely at right-angles thereto (see figures 62 and 63). The mechanical action of this device is like that of the well-known ring clutch. The tail of the lever E′ carries an adjustable screw *e*′, which rests upon a wedge-shaped slide *h*′, which is carried by a horizontally movable shifting lever C as hereinafter described. P is a dash-pot, the operation or function of which has already been explained. Thus from the preceding description it will be understood that when the lever E′ is tilted by the rising of the armature D′, the clutch is thrown into an angular position and grasps and lifts the carbon-carrier R′. As the carbon burns away, the armature, clutch and carbon carrier descend together, until the screw *e*, strikes upon the slide *h*′, by which the clutch is tripped, thus allowing the carbon-carrier and carbon to drop the necessary distance to effect the operation of feeding. The lamp thus feeds by an intermittent advance movement, which under ordinary conditions is about $\frac{1}{32}$ of an inch at each step.

It now remains to describe the mechanism by which the second pair of carbons is substituted after the first pair has been consumed.

The lower terminal of the thick wire helix, D D, is electrically connected with both of the movable upper carbon carriers, and the electric current, as well as the feeding mechanism, are shifted simultaneously, at the proper moment, to the second set of carbons, by the action of an independent shifting magnet M (figures 291 and 293), which is included in a second derived circuit of high resistance between the terminals of the lamp. The shifting lever C carries the wedge-shaped slides h' h', which are inserted under the end of one clutch or the other, according to the position of the lever, so as to trip the proper clutch and prevent it from engaging with its rod.

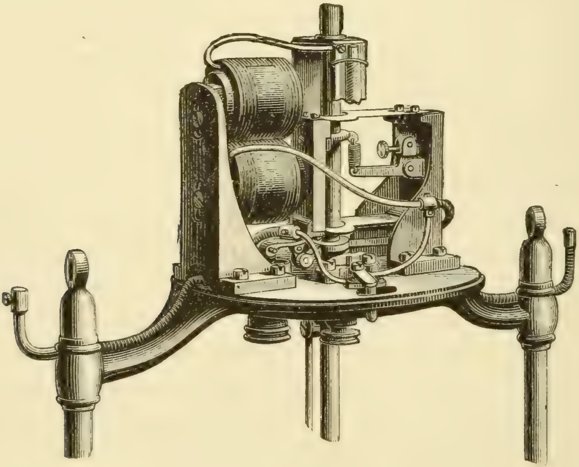

Fig. 294.

While the first set of carbons is burning, the circuit through the shifting magnet M is open; the upper carbon R′ of the second set being held up by the latch L, which engages with a flange N, upon the carbon carrier, and the shifting lever C, is locked by a detent *g* (figure 291), in the proper position to leave the first clutch free and trip the second. When the first set of carbons has been consumed, the derived circuit of the electro-magnet M is completed by a collar, H, on the upper rod R, coming in contact with an insulating ring K, to which the magnet wire W is attached. The shifting magnet then attracts its armature G, and thereby lifts the detent *g* from the shifting lever, allowing it to swing over under the stress of the spring *s* (figure 293), thus reversing the position of the slides under the clutches, and releasing the upper carbon of the second set by the withdrawal of the latch L. As the upper carbon R of the first set remains supported out of contact with its lower carbon by the stop *e*′, the current is diverted to the second set of carbons the instant that they come into contact, and the feeding magnet thereafter works the second clutch instead of the first. This substitution is effected so quickly as to cause scarcely a perceptible flicker in the light.

The sensitivenes and certainty of operation which have been found in practice to characterize the action of the feeding mechanism which has just been described, are largely due to the peculiar arrangement of the armature of the electro-magnet D, which has already been explained, and to the construction and proportions of the clutch. It will be observed that the clutch is provided with a long tail-piece, as the lever E E′ may be termed, and the point of contact of the clutch with the floor of the lamp is at the extreme end of the tail-piece. This gives the detaching point of the clutch a great mechanical advantage over the lifting point, and consequently it requires but a minimum of force to detach the clutch from the rod and allow the latter to feed. Of course the sensitiveness of the feeding mechanism in the lamp depends in practice largely upon the amount of force which is necessary to lock and unlock the feeding mechanism, because this force is derived solely from variations in the strength of the lighting current, due to fluctuations in the length of the arc.

Figure 294 is a perspective view of the mechanism of the single lamp which shows the cut-out or short-circuiting devices, by which the lamp may be instantly switched out of circuit when it is desired to replace the consumed carbons or to perform any other necessary operation upon it.

In figure 295 a more recent form of lamp-frame is shown, in which all the electrical connections are placed inside of the tubular support by which the glass globe is suspended from

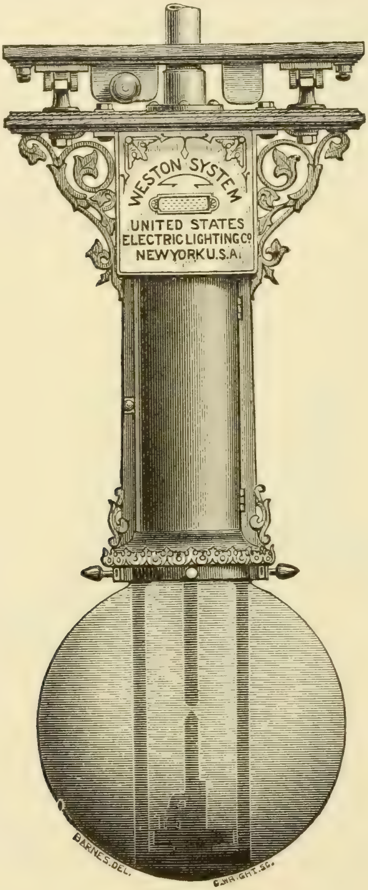
WESTON SYSTEM
UNITED STATES
ELECTRIC LIGHTING Co
NEW YORK U.S.A.
BARNES.DEL.
C.WRIGHT.SC.

Fig. 295.

the casing above, so that no portion whatever of the lamp which is in electrical connection with the circuit is exposed or accessible. This form of frame is employed either for duplex or for single lamps, the same as the form shown in figure 289,

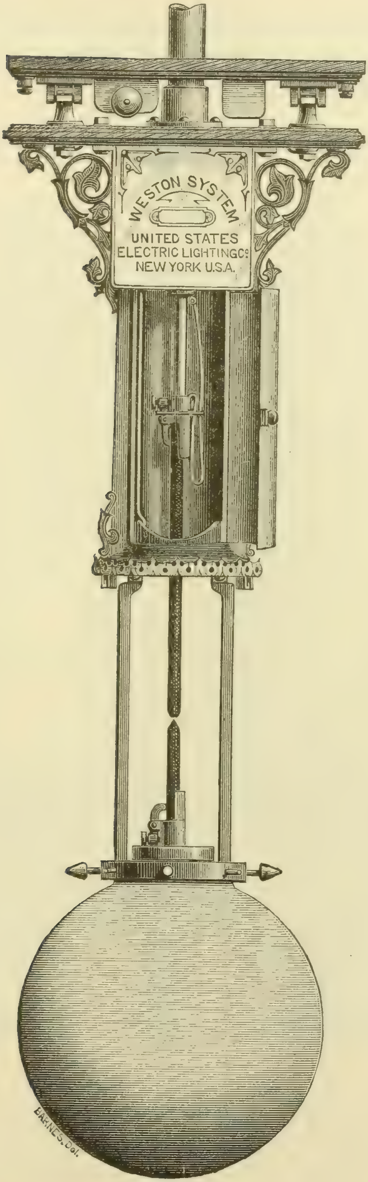
WESTON SYSTEM
UNITED STATES
ELECTRIC LIGHTING Co.
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Fig. 296.

and the same feeding mechanism may be used. Figure 296 shows the manner in which the inner frame is lowered for the purpose of replacing the carbon.

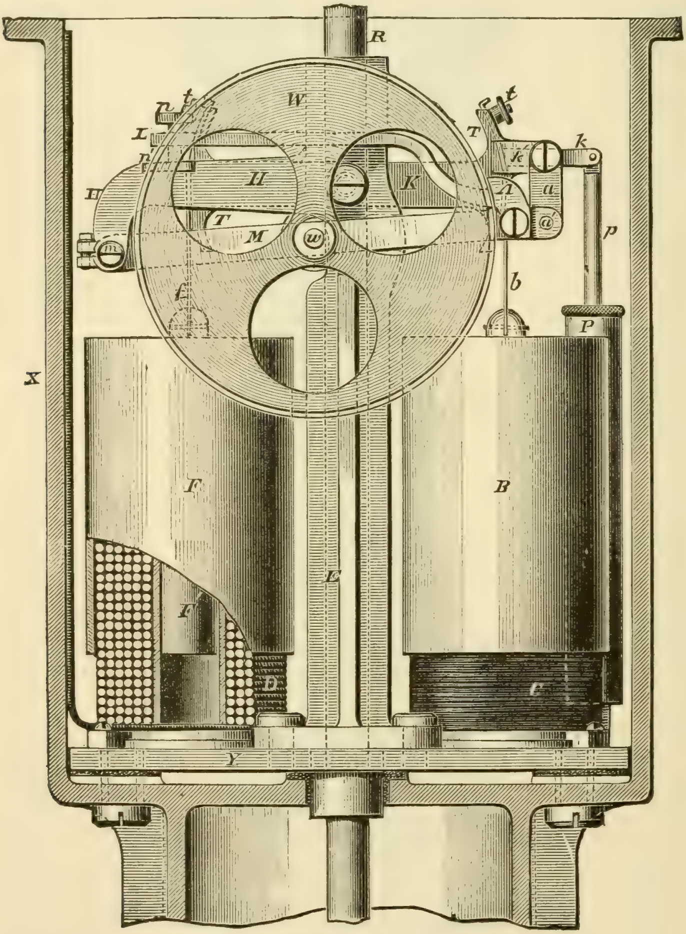

Fig. 297.

More recently, Mr. Weston devised a new form of regulating apparatus, in which the feeding of the carbons is controlled by a brake-wheel, to the axis of which the upper carbon carrier is attached either by a cord and pulley, or by a rack and pinion movement, so that the carrier cannot be moved without turning the wheel. This apparatus is shown

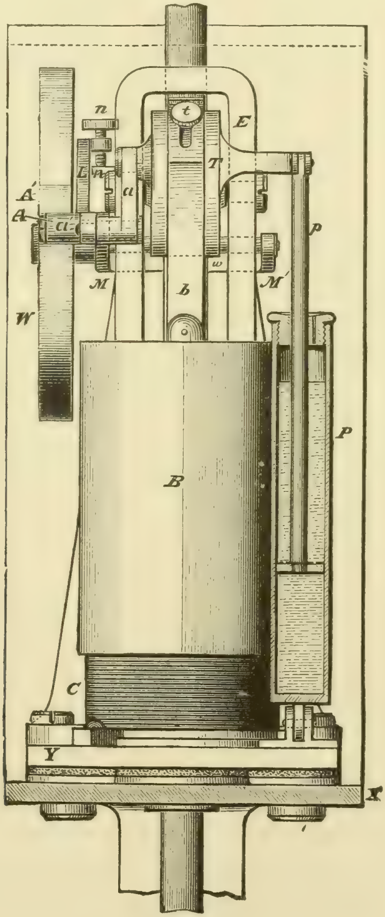

Fig. 298.

in figures 297 and 298. The axis *w*, of the brake-wheel W, is mounted upon a swinging horizontal lever, M, one end of which is pivoted to a fixed support *m*, and the other end is linked to a horizontal oscillating lever K. The hollow helices or solenoids F and B, of peculiar construction, which will presently be described, serve to control the position of the oscillating lever K. One of these solenoids is included in the main or arc circuit, and the other in a derived circuit or shunt spanning the arc. The movable cores or armatures of these solenoids, as shown at F′, are attached to the respective ends of the lever K, by flexible metallic straps, *f* and *b*. The brake-wheel W is held in check by a friction brake, A, which is pivoted to the lever M, just outside of the periphery of the wheel, and has a short arm at the right, to which a lifting link, *a*, is attached at *a′*. It is also provided with a long tail-piece, L, extending over and resting upon a stationary projection from the frame of the lamp at *n′*. The construction of the solenoids is shown at the left, in figure 297, where the external iron shell and part of the coil are cut away to show the interior construction. It will be seen that the solenoid incloses a movable iron core, and in addition an iron shell is attached thereto surrounding the coil, it being made in one piece with the core. Mr. Weston has found that with a solenoid constructed in this manner an extremely long range of movement may be obtained with very uniform power. Experience also shows that this solenoid is nearly as powerful as an ordinary bi-branched electro-magnet, having twice the amount of wire upon it. The disadvantage of the ordinary solenoid is in its great size in proportion to the effective force which it is capable of exerting.

The operation of this apparatus is as follows: Assuming the lamp to be at rest, with the upper carbon in contact with and resting upon the lower one; upon first applying the current the attractive force of the solenoid F will preponderate and draw down its end of the oscillating lever K. This movement raises the brake A, and as soon as its tail-piece, l, is raised sufficiently to lift it from the stop *n′*, locks it upon the wheel. Any further movement of the oscillating lever K carries up the lever M and turns the wheel W with it, whereby the carbons are separated and the arc is formed. As the arc increases in length the force of the solenoid F weakens, while on the other hand that of the solenoid B continually increases, so that a condition of equilibrium is soon reached in which the end of the lever L rests upon the stop with just sufficient force to slacken the brake and allow the wheel to revolve. The slightest decrease in the length of the arc will immediately set the brake, while on the other hand the slightest increase will release it. It will be observed that the brake is so arranged with reference to the wheel that the weight of the carbon and its carrier tends to apply the brake when its detaching lever is lifted from the stop. Its grip on the wheel is therefore very positive; but the wheel being of large diameter, and the detaching point of the brake lever having great leverage over the brake, the device works with the utmost mechanical delicacy. The feeding, under ordinary conditions, is so nearly continuous that it is impossible to detect the movement by the eye.

One of the most recent, as well as the most efficient of the different forms of arc lamps which Mr. Weston has invented is shown in perspective in figure 299. The principal object in view in this particular organization is to simplify and cheapen the construction of the working parts of lamp, and to provide for a greater range of movement of the armature and its attachments. The casing and frame of this lamp are the same as that of the one last described. The regulating or feed mechanism is mounted upon a metallic plate or base, which is secured to the under side of a wooden base-board, as illustrated in the figure. Two electro-magnets are employed, which are placed parallel to each other in a horizontal position, one of them being included in the main or arc circuit, and the other in a shunt or derived circuit spanning the arc. Each magnet is provided with an armature mounted so as to lie in a direction parallel to the axis of its own magnet. These two armatures are rigidly attached to a common rock-shaft, in such a position that the preponderance of the magnetic attraction of one magnet over the other exerts a twisting effect upon the rock-shaft, and thus causes the latter to turn in its bearings, the direction and extent of the movement imparted to it being determined by the magnet which exerts the greater attractive force. The clutch mechanism is fixed upon a level, which moves up or down by the action of a link attached to one of the armatures. This mechanism is substantially the same as that already described in connection with preceding lamps, and will be readily recognized in the figure, so that a repetition of the former description is unnecessary. It is obviously immaterial what particular form of clutch is employed

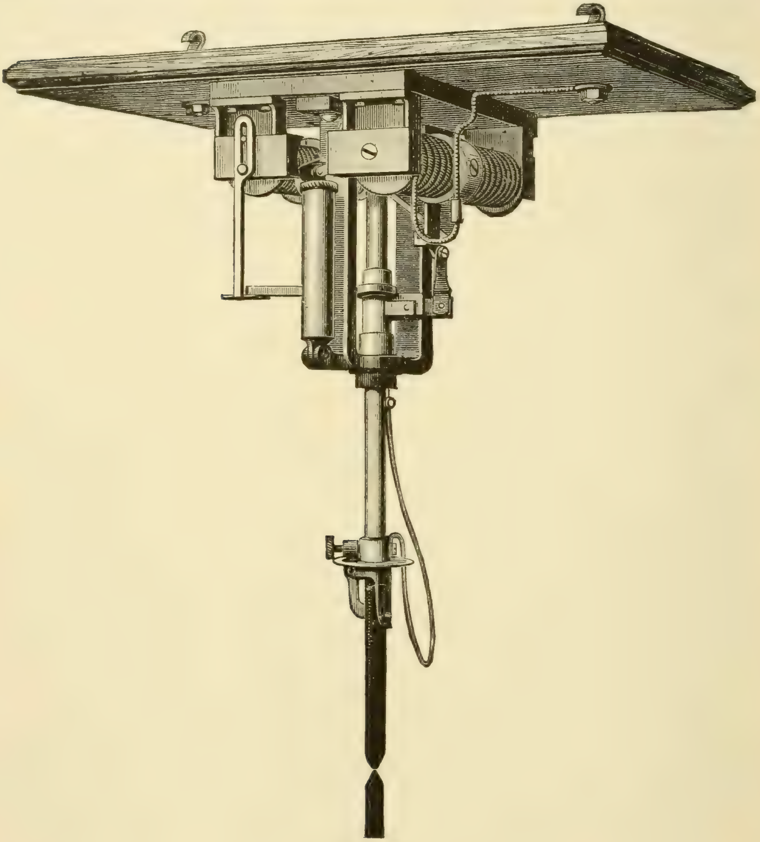

Fig. 299.

in connection with this lamp; the particular one illustrated in figure 299 will, however, be described in detail in connection with another lamp.

Figures 300 and 301 illustrate another exceedingly efficient lamp, also constructed by Mr. Weston. In the first named figure several parts are shown in perspective, a portion of the frame being broken away to exhibit the mechanism more clearly. Referring to the figures: A represents the thick wire coil in the arc circuit, and B the thin wire opposing or differential coil in the shunt circuit. These coils are simple solenoids provided with hollow soft-iron cores a and b, which move freely within them, being maintained in an axial position by guide pins C C.

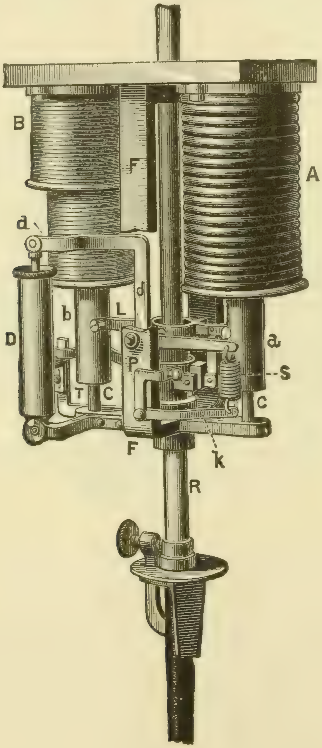

Fig. 300.

The extremities of a horizontal oscillating bar, L, project into slots formed in these cores (see figure 301), and this bar turns upon a horizontal axis at P (see figure 300), from the vicinity of which projects an arm, *d*, extending to the piston of the dash pot D. Another similar arm carries an adjustable spring, S, which serves the same purpose as the corresponding spring in the other forms of lamp which have already been described. The details of the clutch mechanism will be more clearly understood by referring also to figure 302, which is an enlarged transverse vertical section of the same. R is the cylindrical rod which forms the carbon-carrier. L is the oscillating lever or bar, the ends of which are raised and lowered by the cores *a* and *b*, as shown in figure 300, and J is a link which is pivoted to the lever L, and serves to operate the clutch. The latter consists of a sleeve, K, which is capable of sliding freely upon the carbon-carrier R, but has a projection upon one side, to which is pivoted at *i*, a cam, I, the bearing point of which passes through a slot in the sleeve and impinges against the rod R. The end of the cam I is pivoted at *i*, to the link J, from which its motion is received, as already explained. The arm H, which is attached to the cam I, serves to prevent the same from descending too far, by tripping it, or causing it to release its grasp upon coming in contact with the adjustable rest or stop shown at *r* in figure 302. The operation of this clutch needs but little explanation. When the link J is raised, the carbon-carrier R is grasped between the bearing surface of the cam I and the opposite portion of the

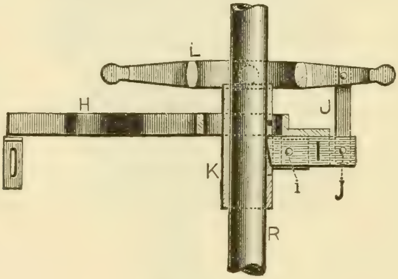

Fig. 301.

sleeve K, and the carrier is lifted with the cam. When the link J is lowered, the cam and carbon-carrier descend together until the angular position of the cam is altered by the arm H resting upon the stop *r*, which trips the clutch and allows the carbon-carrier to descend and effect the operation of feeding.

Figure 303 shows the construction of the automatic cut-out ordinarily used with the different forms of Weston lamps. It is a modification of the so-called Varley cut-out, and comprises an electro-magnet which is placed in the same circuit with the arc, the armature of which is so arranged as to short-circuit the lamp, when the armature is released by the magnet. This has been arranged in a very compact and convenient form, and in practice is usually attached to the supporting base-board above the lamp, as shown in figures 295 and 296, but it may be placed within the casing which protects the feeding mechanism. The diagram shows clearly the electrical connections. The main coil of the electro-magnet is surrounded with a few convolutions of insulated German silver wire of greater thickness, which are included in the shunt circuit. The current in this supplementary coil flows in the same direction as in the main coil, and the object in employing it is to cause the electro-magnet to act more quickly

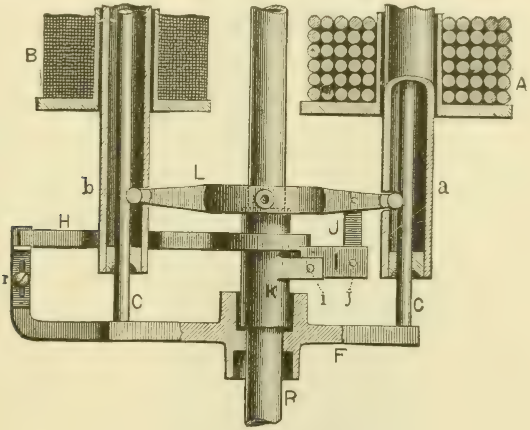

Fig. 302.

to open the shunt circuit, when the lamp is lighted. The resistance of the shunt coil is insignificant (about the same as that

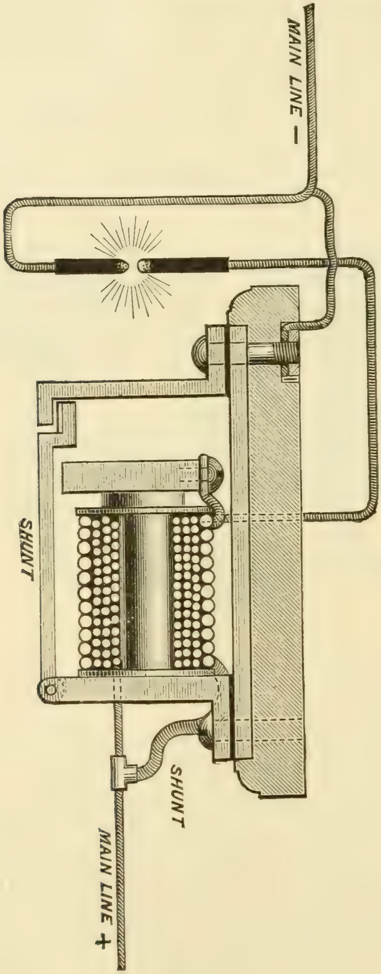

Fig. 303.

of the lamp when the carbons are in contact), and, when the shunt is closed, and the lamp circuit open, it is obvious that the entire current must pass through the resistance, but as it has but few convolutions to traverse, and these at a distance from the core of the magnet, not enough magnetism is developed to lift the armature. Whenever the lamp circuit is closed, the current at first divides between the two coils on the magnet, and both conspire to cause it to lift the armature very quickly. As soon

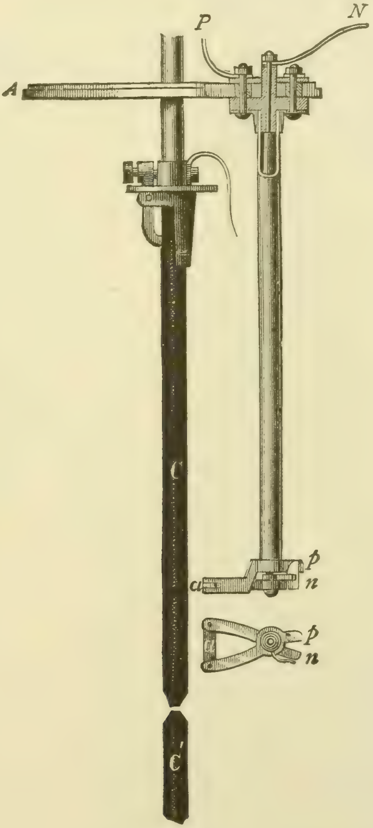

Fig. 304.

as the armature is lifted, the shunt is broken, and the entire current passes through the lamp. This form of cut-out has been found very efficient under ordinary circumstances, but where a very large number of lamps are used in the same circuit, another form of cut-out, shown in fig. 304, is used, which serves as an additional precaution to guard against excessive elongation of the arc.

P and N, fig. 304, are insulated conductors leading from the binding-posts of the lamp, and terminating in the contact surfaces *p* and *n* of a spring switch, located a short distance above the arc, as shown in the figure. This switch, when left free, is closed by the action of a spring, but is normally held open by an interposed plug, *a*, composed of a fusible alloy, which is inserted between the jaws of the switch, as shown in the detached plan view in the lower part of the figure. The switch thus arranged is supported near the upper carbon, but at a sufficient distance above the arc to preclude the possibility of melting the fusible plug while the arc remains of normal length. As is well known, any material increase in the length of the arc develops a very great increase in the amount of heat evolved. In case this occurs, the fusible plug is at once melted, permitting the switch to close and cut the lamp out before the arc can become excessively long. This device is very positive and certain in its action, and has been found to be extremely reliable. It is easily readjusted by simply replacing the fusible plug. It is, however, rarely brought into action in practice, as accidents to the feeding mechanism seldom occur in well constructed lamps and regulators.

A special form of electric arc lamp, which is largely employed on steamboats on the Western rivers, and which is termed a focusing lamp, is shown in fig. 305. This lamp is fitted with a powerful parabolic reflector, similar to that used with the headlight of a locomotive, the object of which is to project all the rays of light proceeding from the lamp in a direction parallel to each other, so as to form a cylindrical beam of light, which may be thrown upon any required spot even at a considerable distance. In order that the electric arc in this lamp may be maintained in the focus of the reflector, it is necessary that both the positive and negative carbon should each be fed forward in proportion to its

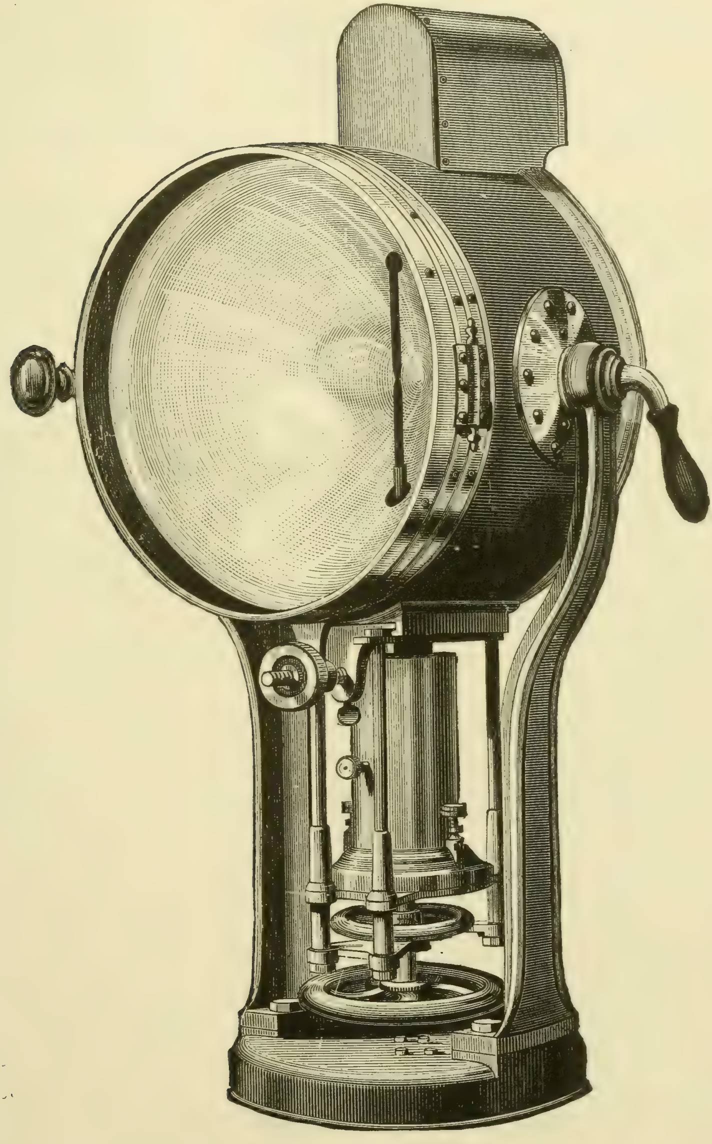

Fig. 305.

normal rate of consumption, the positive carbon being consumed, roughly speaking, about twice as fast as the negative. This double feeding is effected by simple mechanism, whereby the mechanical movement of the regulator is communicated to both carbon-holders in the proper relative proportion.

The Weston lamp in all its varied forms of construction embodies certain essential characteristics which distinguish it from the lamps of other inventors. Perhaps the most important of these is the unusual shortness of the electric arc, which is somewhat less than $\frac{1}{32}$ of an inch, when the lamp is running under normal or average conditions. This renders it possible to employ an electric current of lower potential and of greater volume than that employed in other systems in general use. The normal current of the Weston system is about 20 ampères, while in most other systems it is much less than this, being, for example, about 11 ampères in the Brush system and 10 in the Thomson-Houston system. In both the last named systems the length of the arc is nearly $\frac{1}{8}$ of an inch, or four times that of the Weston.

Several important advantages are gained by the employment of an electric current of low potential. One of the greatest of these is, that danger to life and property is avoided. It is not known that any person has ever been in any way injured by the current used in the Weston system, although instances have occurred in which workmen have accidentally introduced themselves directly into the circuit of a 50-light machine without serious results, under conditions which in the case of most other systems would have been instantly fatal. Another advantage is that a greater amount of light is produced per horse-power of dynamic energy by the Weston system than by any other system of operating lamps in series, according to the official tests made at the Paris Exposition. The report of the jurors gives the following results, showing the amount of light in carcels per horse-power, by several different systems in which five or more lamps were operated in the same circuit:

Weston	system,	10	lights,	65.3	carcels	per horse power.
Gramme	"	5	"	63.8	"	"
Brush	"	40	"	52.1	"	"
Siemens	"	5	"	51.5	"	"
Brush	"	16	"	45.4	"	"
"	"	38	"	44.4	"	"

A further important advantage is in the color of the light, the difference in this respect between the light from a long arc and that from a short one being of a marked character. The excessive proportion of blue and violet rays in the long arc light impart to it a peculiar color which is often exceedingly disagreeable to the eye. The illuminating effects of the short arc are due almost entirely to the incandescence of the carbon electrodes, and the color closely resembles that of sunlight, being softer and more agreeable to the eye, an especially important consideration when the light is to be used for interior illumination. The frequent occurrence of small particles of foreign substances in the carbon, which produces an almost constant tremor in a long arc, does not perceptibly affect the uniformity of light from a short arc. The only disadvantage of the short arc system is, that somewhat larger line conductors or mains are required to convey economically the greater volume of current which it is necessary to employ, but this disadvantage is scarcely worth consideration in view of the important results above mentioned, and which could not otherwise be obtained.

The great suspension bridge between New York and Brooklyn affords a very interesting example of the application of the Weston system of lighting, this system having been selected by a committee of the Board of Trustees, after an unusually thorough investigation of the whole subject, the principal considerations which influenced the final selection being those of economy and safety. The accompanying illustrations will serve to give some idea of the general effect produced by the lights, together with some of the more interesting details of the construction and arrangement of the plant. The illumination of the entire structure, including the bridge and its approaches, requires 70 lamps of the duplex pattern, arranged in two circuits of 35 lamps each. Of these, 14 are situated on the main span between the towers, 50 on the approaches at either end, and the remainder are distributed in the stations at each end, and in the engine house. The two electric circuits are in every respect independent of each other, and are so arranged that each alternate lamp is in a different circuit, so that any accident or fault occurring in one circuit, will leave no portion of the structure in darkness. This arrangement is shown in the diagram, figure 306, in which the small crosses represent the lamps arranged alternately on the different circuits. The total length of the bridge, together with its approaches, is more than a mile, so that the two lighting circuits contain a total of more than four miles of main conductor. Each circuit is worked by two twenty-light Weston dynamos, coupled together in series, and driven by an independent horizontal steam engine. The dynamos and engines are located in the main engine house at the Brooklyn end of the bridge, as shown in the plan, figure 306. Figure 307 is an interior view of this engine room, showing the four dynamos and the horizontal steam engines by which they are driven, and also a portion of the large engine which propels the endless cable for drawing the railway cars across the bridge. An additional safeguard against the extinction of the lights has been provided in this case by the establishment of special conductors connecting the New York terminus of the bridge with one of the regular electric lighting stations of the United States Illuminating Company in that city. Switch mechanism has been provided at both ends of the bridge, as shown at A A (figure 306), so that in case of accident to the engines or dynamos, by closing the switches at the Brooklyn end, and opening those at the New York end, the bridge circuits are interposed as loops into the lines leading from the illuminating station.

The form of lamp post and reflector which is used on the bridge is shown in figure 290.

Figure 308 shows the main conductor in its actual dimen-

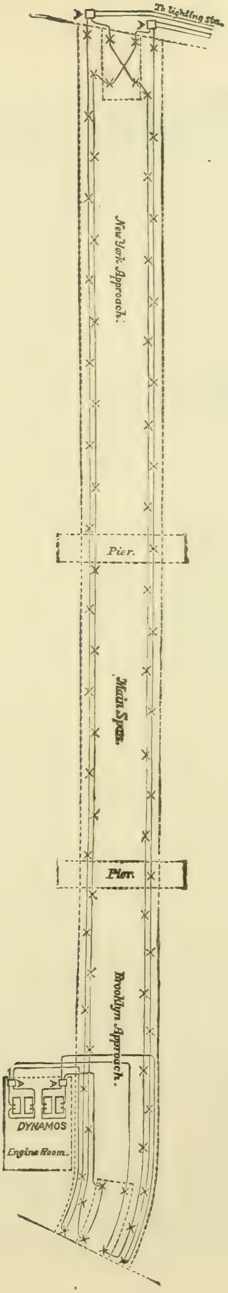
To lighting sta.
New York Approach.
Pier.
Main Span.
Pier.
Brooklyn Approach.
DYNAMOS
Engine Room.

Fig. 306

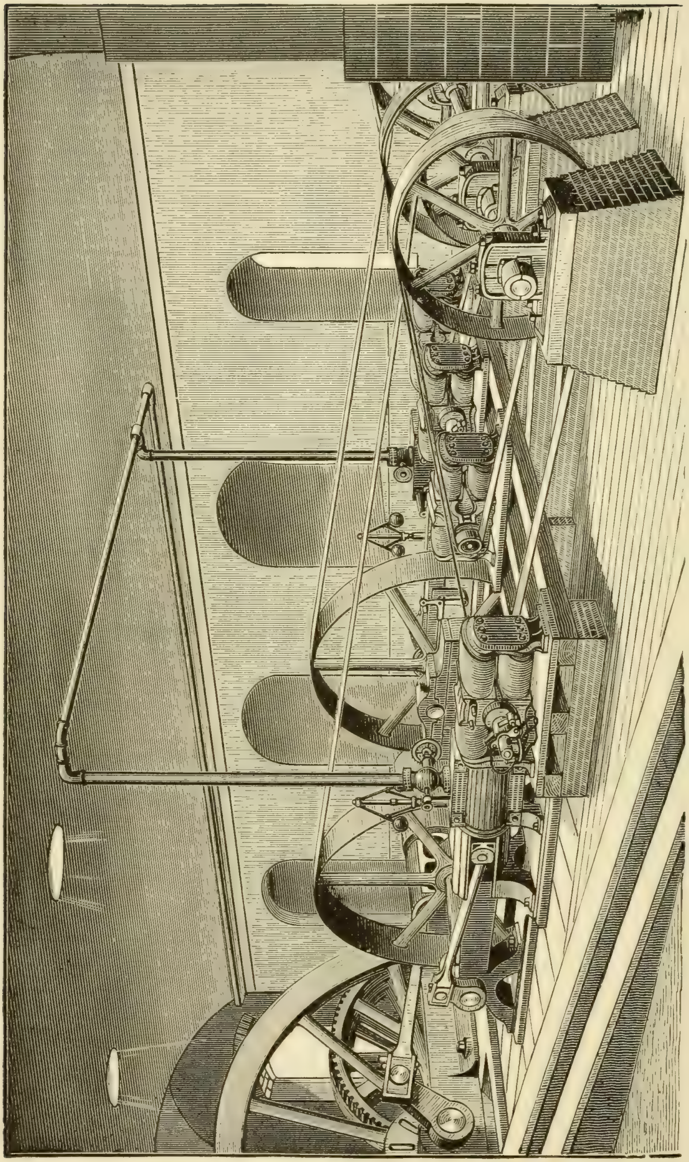

Fig. 307.

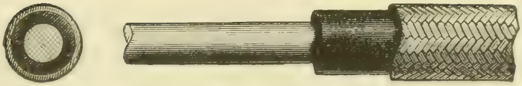

Fig. 308.

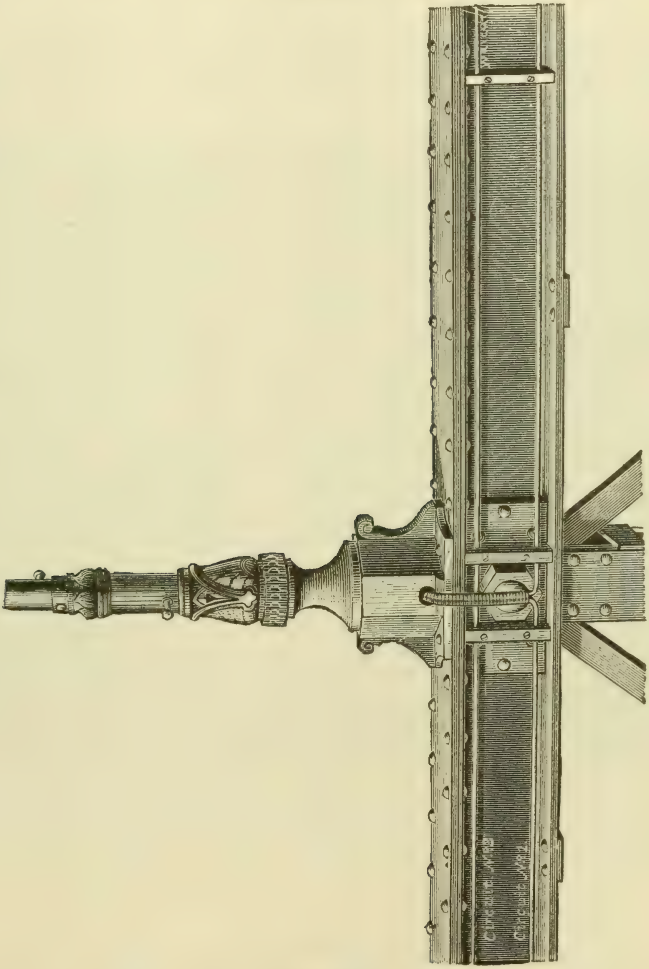

Fig. 309.

sions. It consists of a heavy copper wire provided with an insulating coating, and having a fire and waterproof protection applied to its exterior. Figure 309 shows the base of one of the hollow iron lamp posts and the manner in which it is mounted upon one of the girders of the bridge, and also illustrates the manner in which the wires are conducted along the iron girder, by being led through wooden blocks or cleats which are fastened between the flanges of the girders, the wires being led into the hollow bases of the lamp posts, as shown in the figure, safety against accident being insured by an external wrapping. Figure 310 gives a very good idea of the general effect of the illumination at night.

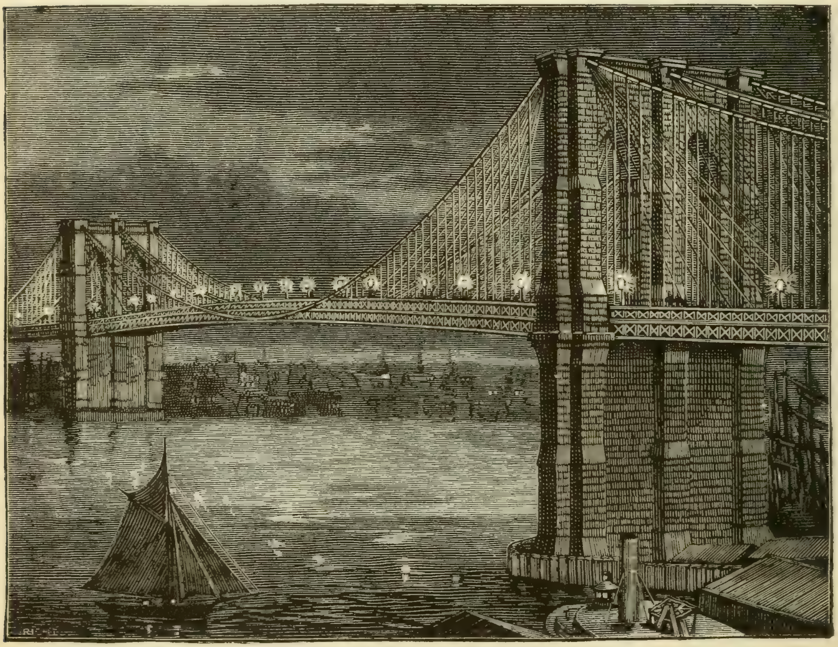

Fig. 310.

In the practical application of the Weston system under the variety of circumstances which are necessarily met with, it has been found necessary to invent and apply a number of supplementary or accessory devices, such as automatic regulators, circuit-indicators for calling attention to accidental derangements of the apparatus, switch or cut-out boxes for switching out lamps or groups of lamps, and other similar requirements. One of the most interesting of these accessories is the automatic regulator

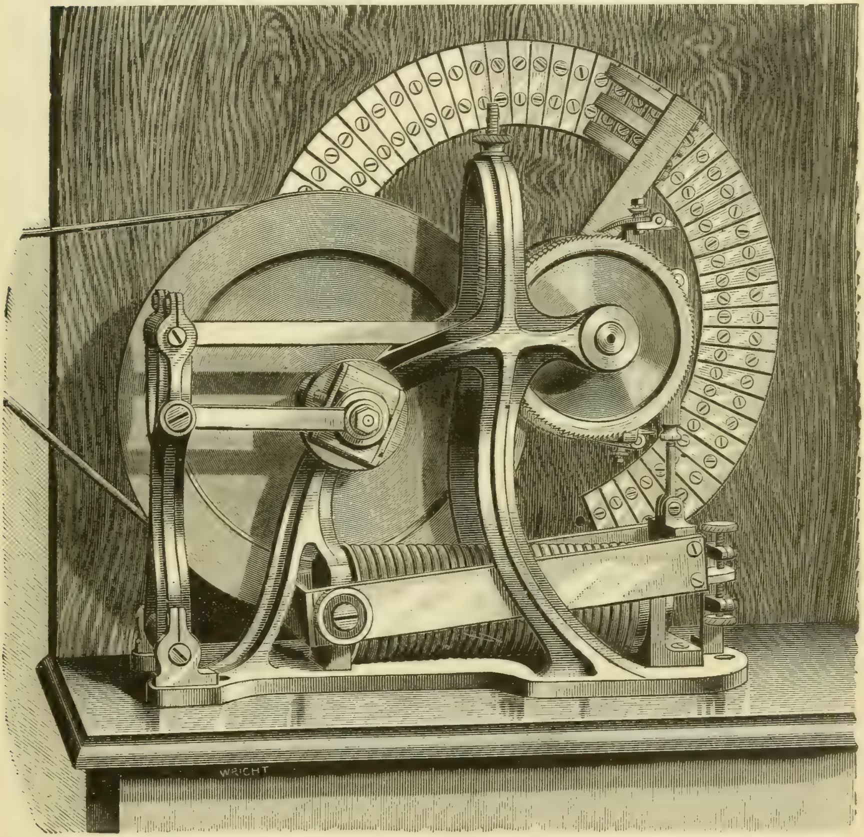

Fig. 311.

for the arc system, which is illustrated in figure 311. Upon the upright portion of the frame or base-board is a sectional commutator or sunflower, over which sweeps a metallic arm carrying a set of contact-springs. This commutator is included in the circuit of the field magnet of the dynamo-machine, and the movement of the arm in one direction or the other gradually increases or decreases the resistance in the exciting circuit as it passes over the commutator. The apparatus is driven from any convenient motor by a small belt, which passes around the large pulley shown at the left of the machine. A short crank or eccentric on the front end of this pulley communicates a constant to-and-fro movement to an upright arm which is pivoted to the left end of the metallic base of the instrument. A longitudinally vibrating horizontal bar pivoted to the upper end of this arm carries two pawls or dogs, which engage respectively, though not both at the same time, with the teeth of a double reverse ratchet-wheel affixed to the commutator arm. A horizontal electro-magnet is placed upon the base of the machine, which acts upon a vertically swinging armature, whose angular position is determined by the attractive force of the electro-magnet exerted in opposition to a spring. The mode of operation of this apparatus is so apparent as to require but little explanation. If the current in the arc circuit becomes too strong, the armature of the magnet is drawn down, one of the oscillating pawls is brought into engagement with the teeth of its corresponding ratchet-wheel, and the commutator arm is moved over a sufficient number of divisions of the commutator so as to increase the resistance in the circuit of the field magnet until the current generated by the dynamo is reduced to its normal amount. So long as the current remains constant neither of the two pawls are engaged with their corresponding ratchet wheels; but whenever it increases or diminishes the proper amount of resistance is automatically inserted into or withdrawn from the field circuit.

In figures 312 and 313 is shown an indicator designed for use in central stations, and other places where the lamps are at a considerable distance from the machine. The coils of the electro-magnet shown in figure 313 are included in the circuit with the lamps, and the tension of the retractile spring of the Z shaped armature is so adjusted as to bring the index hand which is attached to its axis, to zero point on the scale, when the current is at its normal strength. Should the current exceed or fall below this strength, however, either the magnet or the spring preponderates, as the case may be, and the index is moved in one direction or the other, thus indicating the direction and extent of the change; and in case of any considerable variation, one of the contact-springs on the lever completes a battery circuit, by making contact with a stop screw in the upper part of the box, and sets an electric bell ringing to call the attention of the attendant. By means of this indicator, the attendant at the central station can see, upon starting the machine, that the normal current is going out to the lamps, and is instantly notified when any accident occurs to the circuit, or when lamps are put into circuit

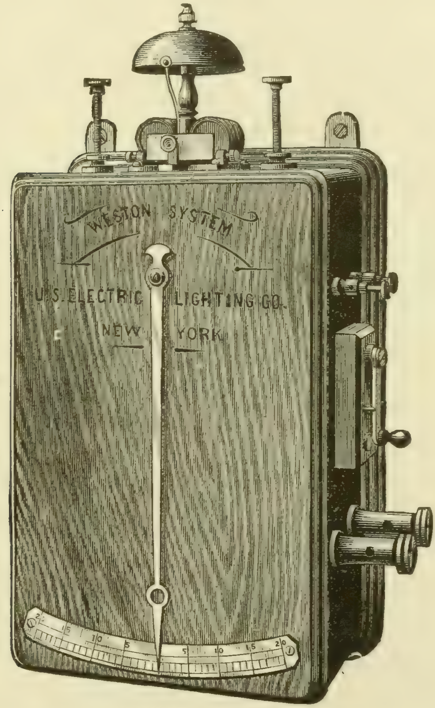

Fig. 312.

or cut-out, so that he can immediately adjust the resistance in the field magnet of the dynamo machine to compensate for the change.

Figure 314 shows an automatic regulator and current indicator mounted in an ornamental case, which may be placed in any convenient position on the walls of the building or office.

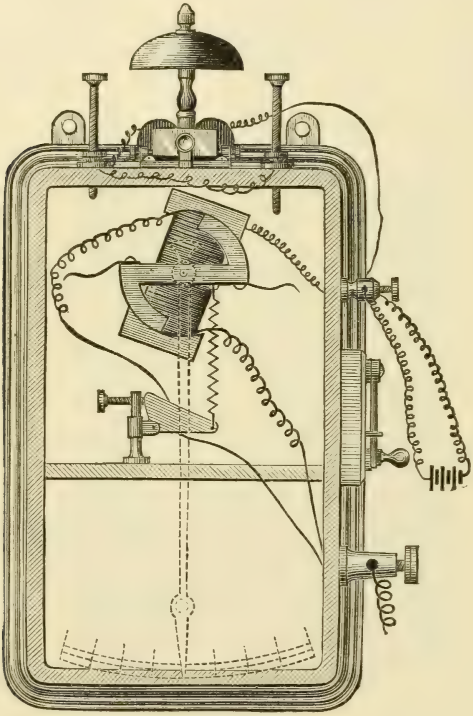

Fig. 313.

The details of the indicator are shown in figure 315, and are essentially the same as those already described.

Figure 316 shows the external appearance of a box which contains devices for the purpose of cutting lamps or groups of lamps into or out of circuit. Upon opening the box an inner compartment is exposed, as shown in figure 317, in the centre

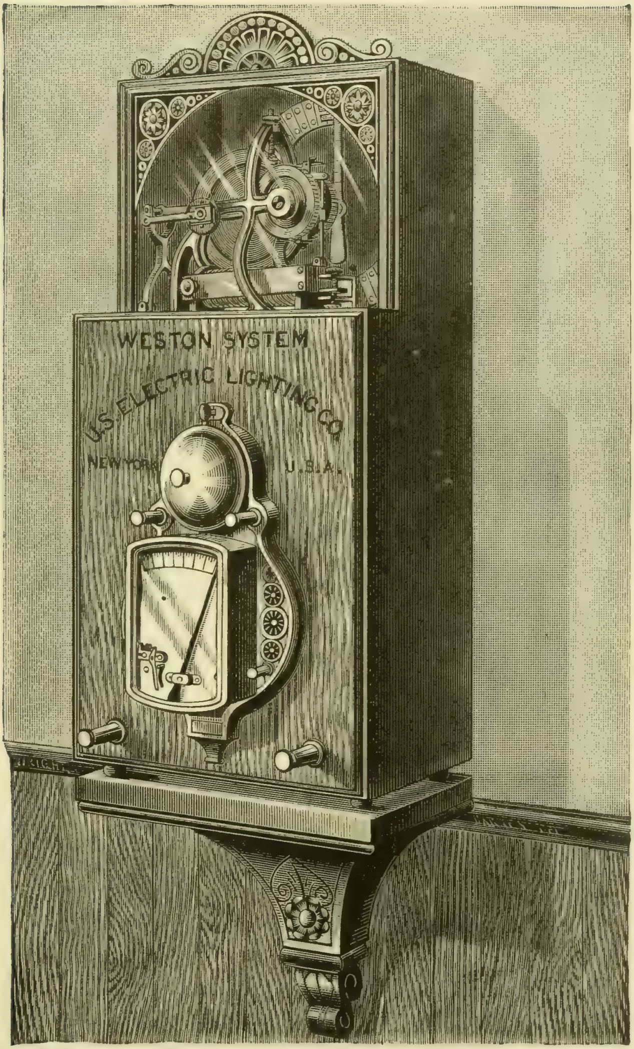
WESTON SYSTEM
U.S. ELECTRIC LIGHTING CO.
NEW YORK
U.S.A.

Fig. 314.

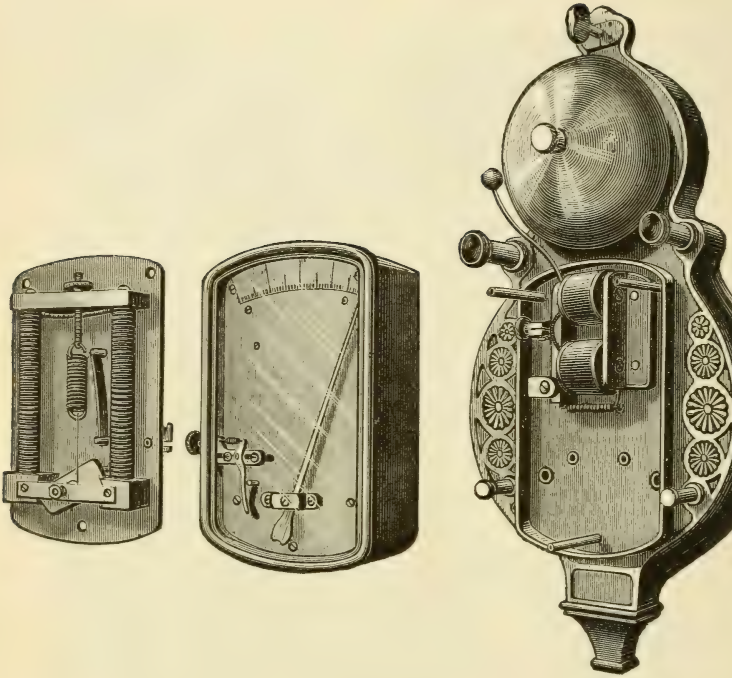

Fig. 315.

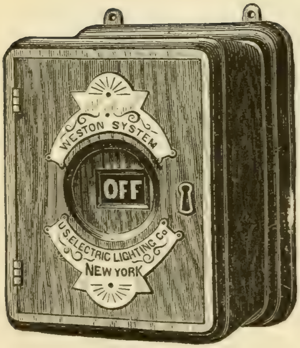

Fig. 316.

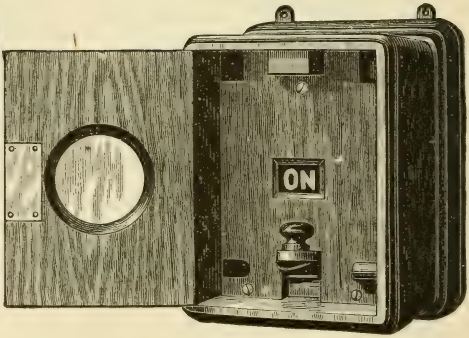

Fig. 317.

of which, at the bottom, is a projecting knob, and at the right a projecting lever. Above is a small window through which appears either the word *on* or the word *off*, according to the position of the electrical connections within the box. The internal construction of the box is shown in figures 318 and 319, which are vertical transverse sections at right angles to each other. Upon a shaft, A, are mounted insulated metallic cylinders, *b* and *c*, which are placed in connection with the electric mains *w w*, by means of flexible conductors, one of which is shown at B in figure 319. Upon these metallic cylinders are fixed resilient metallic contact arms, B and C, which, when the cylinder turns upon its axis A, are caused to move over the surface of pairs of

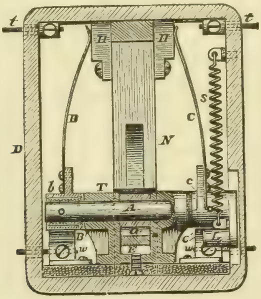

Fig. 318.

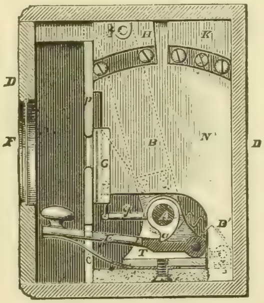

Fig. 319.

metallic contact plates, H and K, which are mounted on opposite sides of a central insulated partition, N. The wires *t t* lead to the lamp or group of lamps, which is designed to be controlled by the cut-out, and these are electrically connected with the contact plates H H, as plainly seen in figure 318. Similar plates, K K, are connected directly together. A strong spring, *s*, is attached to an arm or lever, L, projecting from metallic cylinder *c*, and tends to throw the spring contact-arms B and C into contact with the plates K K, but is normally restrained by a projecting detent, *a* (figure 319), which engages with a notch upon the lever E, the whole being held in position by a spring, *c*. The lever E projects through the front of the case and is provided with a knob as shown. An arm, *g*, projecting from the axis A, moves a slide G, upon which are fixed the words *on* or *off*, one or the other of which is shown through the window in the front partition, according to the position of the spring contact-arms B and C. In the position shown in figures 318 and 319, the current passes through the spring contact-arms B and C and through the wires *t t*; but if the knob attached to the lever E be depressed, disengaging the detent *a* therefrom, the spring *s* instantly throws the contact-arms over to the contacts K K, thus completely detaching the wires *t t* from the line and instantly restoring its continuity through the contacts K K. The lamps are placed in circuit by simply depressing the lever L at the right of the box, which restores the apparatus to its normal position, as shown in the figures.

THE DE MERITENS CANDLE.

M. de Meritens' candle differs from the ordinary Jablochkoff candle only in having a thinner carbon pencil placed between the other two, from which it is insulated in much the same way. The two outer carbons are connected to the machine, and the arc passes between them, the intermediate carbon acting merely as a bridge or stepping stone to enable the current to pass across under variations of strength. M. de Meritens claims for this form of construction the merit of greater steadiness of the light.

THE HEDGES ARC LAMP.

This lamp consists of two troughs, so inclined as to form the letter V, within which two carbons slide, and when no current is passing, meet at the bottom. One carbon holder is fixed and the other pivoted to the frame; the motion of the latter being controlled by an electro-magnet, by which, when the current traverses the lamp, the carbons are separated, thus forming the arc. The positive carbon is held from sliding by the pressure of a smaller carbon, so fixed as to be slowly consumed as the other is burned away. The negative carbon holder has an adjustable platinum stop, which, by pressing against the side of the conical end of the carbon, prevents its sliding down faster than it is consumed.

THE McCARTY ARC LAMP.

Figs. 320 and 321 give a general view of the McCarty lamp, manufactured by the White House Mills, of Hoosick, N. Y. The carbon rods and carbons are inclosed in a globe and hood, and the parts through which the current passes are insulated. The mechanism for controlling the arc is placed at the bottom of the lamp, which facilitates the construction of side wall fixtures. The carbon rod is held by a magnet placed in the main circuit, while the feed is controlled by a second magnet. Each lamp contains an automatic cut-out.

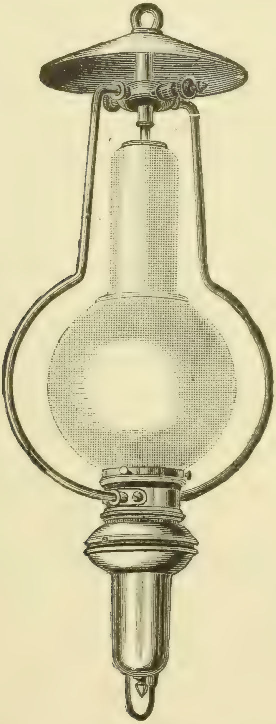

Fig. 320.

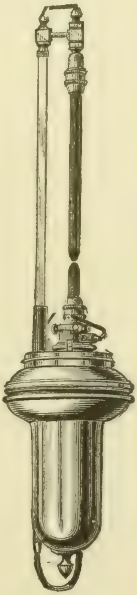

Fig. 321.

CHAPTER VII.

DYNAMO-ELECTRIC GENERATORS.

Dynamo-electric generators are machines for converting energy, in the form of dynamical power, into energy in the form of electric currents, by rotating metallic conductors—usually copper wire or rods—in a magnetic field. The term dynamo-electric machine appears to have been first employed by Dr. Werner Siemens, of Berlin, in 1867, to designate a self-exciting machine, which converted dynamical power into electrical power without the aid of permanent magnets. Previous to this, all machines for generating electric currents by dynamical power were called magneto-electric machines, and this term has been generally retained since to designate those whose fields are excited by permanent magnets. But since the recent great development of electric lighting began, it has sometimes been found convenient to use generating machines in which the self-exciting principle is not employed. Some systems of electric lighting require alternating currents, produced by machines which are incapable of exciting their own magnets; and other systems employ continuous currents, which experience has shown are better regulated when the magnets of the dynamo-electric generators are separately excited from an external source. It is thus apparent that the limitations of the term dynamo-electric machine to one particular class of machines has no logical foundation. A dynamo-electric machine is one, in fact, whether its magnets are excited by its own currents or by a current from an independent source. The source of the magnetizing power is immaterial, provided a magnetic field of sufficient strength be produced wherein the generating coils can be rotated; and as it does not matter where the magnetizing power comes from, it is evident that we ought to include among possible sources the power derived from permanent magnets. The arbitrary distinction, therefore, between so-called magneto-electric and dynamo-electric generators fails when critically examined. In all of these machines a magnet, whether permanently excited, independently excited or self-excited, is employed to provide a field of magnetic force, and in all of them dynamical power is employed to do the work of rotating the coils of the armature, in order to generate the electric currents; and hence the term dynamo-electric machine is equally applicable to all. Before describing the various forms of dynamo-electric machines in use, let us examine the principles upon which they are founded and the successive steps which led to their development.

ELECTRO-DYNAMIC INDUCTION.

It was known at a very early period that a magnet is capable of magnetizing a piece of iron which is brought near it, though not in contact with it; and also that the electricity developed by an electrical machine electrifies, by action from a distance, every body in the neighborhood of the conductor. To these phenomena Faraday added, in 1830, the important discovery that a galvanic current is able to induce other galvanic currents in neighboring wires without actual contact. The process by which these additional currents are produced is called electro-dynamic induction. The currents generated are called secondary currents, and the generating current is called the primary current.

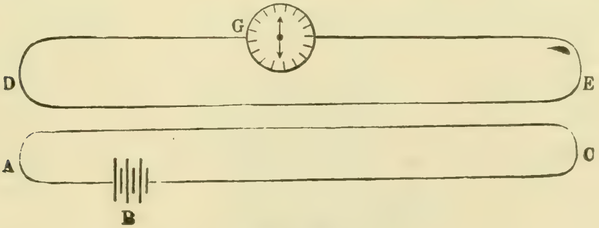

Fig. 322.

The principal law of electro dynamic induction is the following: If a conducting circuit is in proximity to a wire connected with an electric generator, then, at the moment when a current arises or ceases in such wire, a secondary current of momentary duration originates in the neighboring circuit. To illustrate this phenomenon, let us suppose B, fig. 322, to be an electric generator, and A C the wire which connects the poles of this generator, in the vicinity of, and parallel to which, is the wire D E, whose extreme ends are connected to a galvanometer, G, capable of indicating the presence of an electric current. As the wire D E is not connected with the generator, no current circulates through it, and the magnetic needle of the galvanometer G remains at rest. Now, as soon as the circuit of the generator B is closed, and a current traverses the wire A C, a current also originates in the second wire, D E, whose presence is immediately indicated by the galvanometer G, and whose direction is opposite to that of the primary current. If we suppose the current in the primary wire to flow from A toward C, then the secondary current in the neighboring wire will flow from E toward D.

The secondary current is almost instantaneous, continuing but a moment and then disappearing, although the primary current continues to flow in the wire A C. The moment the primary circuit is closed, the needle of the galvanometer G is suddenly deflected, indicating by its movement the formation of the secondary current, when it returns immediately to a state of rest, and remains thus during the continuance of the current in the wire A C.

As soon, however, as the circuit of the generator B is opened, a secondary current appears in the wire D E simultaneously with the disappearance of the primary current. This is also of momentary duration, and traverses the wire in the same direction as the disappearing primary current. As we have seen, if the primary current circulates in the direction from A to C, then the secondary current which originates in wire D E, when the primary circuit is opened, will be in the same direction as the primary current, or from D to E, while the secondary current, which arises when the primary circuit is closed, is in the opposite direction, or from E to D.

The passive condition of the wire while thus under induction, has been described by Faraday as electro-tonic. An electric throb marks the setting in of this state, and another its vanishing, the former in an opposite direction to that of the inducing current, and the latter in the same direction. If the primary wire A C be movable, so that it can be suddenly brought near to and withdrawn from the secondary D E while the primary current passes steadily, currents are induced as in the former case, the approach of the wire being marked by an inverse current and its withdrawal by a direct one. As long, however, as the primary wire remains in any one position, all evidence of electricity in the secondary wire disappears; but if in this position the strength of the primary current should be increased or diminished, momentary currents in the secondary wire would again mark the changes in the primary, the increase causing an inverse and the decrease a direct current. Hence, we conclude that a current which begins, a current which approaches, or a current which increases in strength, induces an inverse momentary current in a neighboring conducting circuit; and that a current which stops, a current which retires, or a current which decreases in strength, induces a direct momentary current in a neighboring circuit. The strength of the secondary current is proportional to the strength of the primary current, to the prox-

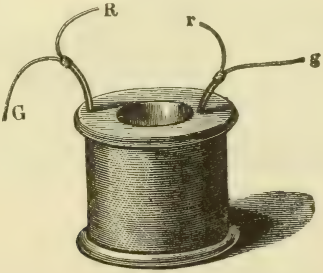

Fig. 323.

imity of the secondary to the primary wire, and to the length of wire subjected to the inductive action.

The latter consideration serves as a guide in constructing apparatus by means of which powerful induction currents are to be produced. These consist, as shown in fig. 323 of two distinct wires brought close together, which are very carefully overspun with silk to insulate them from each other, and then wound for a great length in the same direction close together on a wooden bobbin. The primary wire R *r*, through which the current from the generator is conducted, is much thicker than the secondary wire, G *g*, forming the induction coil. In some instances, each of the two wires is wound upon a wooden bobbin, cylindrically grooved, and so arranged that the coil of the primary wire may be placed inside of the hollow coil consisting of thin wire. In all cases, the ends of the thick wire are connected with the generator, while the ends of the thin wire are either

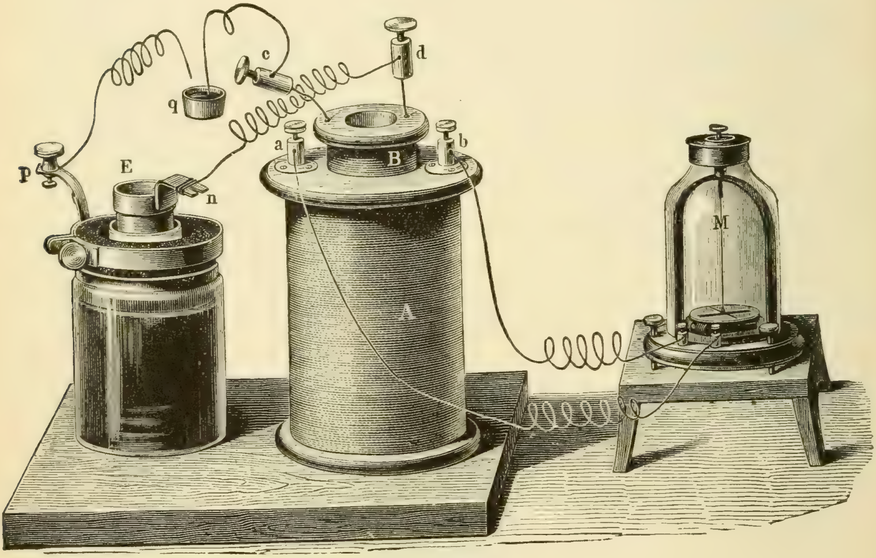

Fig. 324.

connected to each other, or to the parts through which the secondary current is to be conducted.

Fig. 324 shows the construction of these parts. A is the secondary coil, consisting of a long, fine wire; B is the primary coil of thick wire, E the generator, and M the galvanometer. The extreme ends *a b* of the coil A are connected with the galvanometer, and the ends *c d* of the thick wire, by means of a mercury cup *q*, with the poles *p n* of the generator. When in a state of rest the needle of the galvanometer indicates that there is no current circulating in the coil A. When, however, the circuit is closed at *q*, then the movement of the needle at M indicates that the coil is being traversed by a current which is in an opposite direction to the current of the coil B. When the primary circuit is opened the needle again moves to nearly an equal distance in the opposite direction. As long as a current traverses the wire B the needle of the galvanometer remains at rest, although any sudden increase in it will induce a current of opposite direction in the secondary wire A; on the contrary, any sudden decrease of the current strength in the primary wire causes an induced current in the secondary wire in the same direction. If the primary wire be brought nearer to or removed further from the secondary wire, the same effect is produced. That is to say, if the thick wire of the coil B, while traversed by a current, is brought suddenly nearer to the thin wire of the coil A, or, what amounts to the same thing, if the coil B, while traversed by a current, is suddenly inserted into the coil A, a secondary current originates in the coil B, which is opposite to the primary current. By the rapid withdrawing of one coil from the other, another secondary current is generated, which is in the same direction as the primary current.

THE EXTRA CURRENT.

To generate a secondary current, it is not necessary that two distinct wires should be employed, as inductive action also takes place between separate convolutions of the same wire, when wound in the form of a heliacal coil. At the instant that an electric current is sent through such a coil, an induced current is set up in it, which opposes and therefore weakens the originating current. So also upon breaking the originating current, an induced current is again set up in the coil, this time in the same direction as the originating current, and adding to its strength. The longer the wire of the coil and the greater the number of its convolutions, the more powerful will be the induced current, which, when generated in the same wire in which the primary current flows, is termed the extra or counter current. It is on account of this extra current that the shock which the human body experiences when the primary circuit is closed is far less intense than at its breaking. One of the principal reasons of the lack of success which has hitherto attended all attempts to construct motors by the use of large electro-magnets, is this action of the extra current upon the primary current, which interferes with the rapid charging and discharging of the magnets.

In consequence of the appearance of the extra current in opposition to the primary current, at the moment of closing the current, the primary current does not attain its full strength, either in a heliacal coil or in a very long straight wire, at the first instant of closing, nor does the current disappear instantaneously when the circuit is broken. A gradual increase of the current takes place upon the closing of the circuit, and it is not until after the lapse of about a fifth of a second that it attains its maximum strength. When the coils surrounding the iron core of an electro-magnet are included in the circuit, this time is lengthened to about three-fourths of a second before the current, and consequently the magnetism of the iron cores can attain its maximum strength. This is one of the reasons why it is not possible to telegraph with the same rapidity on long lines as on shorter ones, and also explains the fact that in all electro-magnetic motors it is impossible to increase the speed beyond a certain limit. Like the ordinary induced currents, the extra currents possess all the qualities of those derived from galvanic or electro-dynamic generators.

MAGNETO-ELECTRIC INDUCTION.

We have seen that when a primary wire traversed by a current is suddenly brought near to, or removed from a secondary wire, a momentary current is induced in the latter. Precisely the same result follows if, instead of the primary wire, we employ a magnet. For instance, if we suddenly place within the fine wire coil A (fig. 325), a magnetic bar, N S, a momentary current will be induced in the wire of the coil, provided its ends are

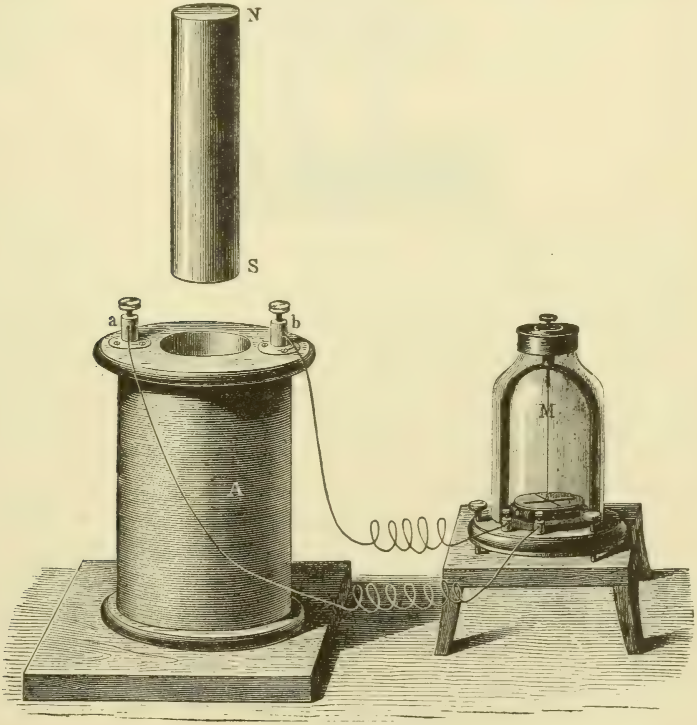

Fig. 325.

conductively connected. As long as the magnet remains at rest no induced current is manifested, but if it be suddenly removed, another induced current arises in the coil, the direction of which is opposite to that of the former one. The direction of both of these currents, which are in all cases opposed to each other, depends upon the polarity of the end of the magnet which is turned toward the coil. By causing a magnet and a coil of wire to be alternately brought near to and withdrawn from each other in rapid succession, momentary induced currents, flowing alternately in opposite directions, are produced in the wire, and by this means very powerful electric currents are obtained by the mere movement of a powerful magnet in proximity to a wire coil.

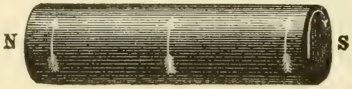

Fig. 326.

The direction of the current induced in a closed wire coil and acted upon by a magnet, depends upon the direction of the motion, the direction of the turns of wire, and to the polarity of the end of the magnetic bar which is nearest when the wire coil is set in motion. To determine beforehand the direction of the induced current, which will be produced by the motion of a magnet, we must consider the magnet as a system of galvanic currents which surround the iron core perpendicularly to its length, and then look at the south pole and imagine the magnetic bar, as in fig. 326, surrounded by currents which pass around the pole in the direction of the hands of a clock. If in this way we suppose the magnet to be a system of electric currents, the same rule applies with regard to the direction of the induced currents produced by the movements of the magnet, as were given on page 520 for the direction of the secondary currents, produced by the primary currents.

The induced current which is generated in the coil A, when the south pole S (fig. 325) is inserted into it, has a direction opposite to that of the hands of a clock, without reference to the direction of the turns of the coil. Therefore, upon the front side of the coil A, which is turned toward the spectator, the induced current passes from right to left. When the south pole is withdrawn from the coil the induced current is in the opposite direction, or from left to right.

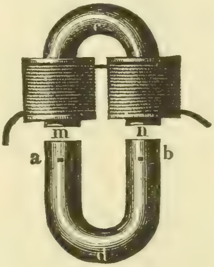

Fig. 327.

Instead of making use of a magnet and a wire coil, as above described, we may enclose a piece of iron, in the form of a horseshoe, *c* (fig. 327), within a helix of wire, and induce magnetism in it by bringing it rapidly into proximity with a steel magnet, *a b*. Thus, when we bring the soft iron *c* near a steel magnet, the iron itself becomes magnetic; and hence the movement of the iron core *m* and *n* toward the poles *a* and *b* gives rise to the same action as that which occurs when a magnet moves toward a wire coil. By the removal of the soft iron *c* from the magnet *a b*, it again loses its magnetism, and thus the withdrawal of the iron cores *m n* from the poles *a b* gives rise to precisely the same phenomena which occur when a magnet is removed from a wire coil.

If, therefore, we give the iron core *c* with its helices a rotary motion, so as to cause the extreme ends *m* and *n* to pass close to the poles *a* and *b* of the permanent steel magnet, then, when the end *n* moves away from the pole *b*, and *m* from *a*, the removal of coil *n* from the south pole *b* causes an induced current in the same direction as the current which arises upon the removal of coil *m* from the north pole *a*. In order to clearly understand this, we must bear in mind that the direction of the turns of the wire coil, represented in fig. 327, exactly correspond to those of the wire in the helix of an electro-magnet.

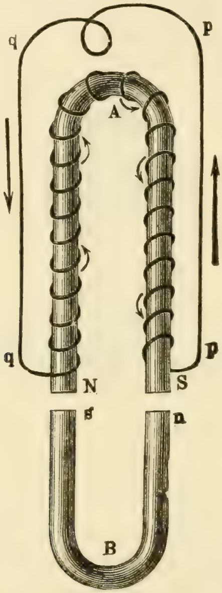

Fig. 328.

Fig. 328 represents an electro-magnet in which the turns are somewhat separated from each other. When the non-magnetic horseshoe A is brought near to the permanent steel magnet B, there arises in the former a magnetic action. A north pole, N, is suddenly formed opposite to the south pole *s*, and a south pole, S, opposite the north pole *n*. The effect of this magnetic action upon the helix is the same as if the north pole of a magnet were inserted into it at N and a south pole at S; that is, a current is induced in each branch. The directions of these currents, as indicated by the arrows, are apparently opposite to each other in the two branches, but are really in the same direction, and mutually reinforce each other in the wire *p q*. During each half revolution of the helices *c* (fig. 327) two induced currents in the same direction are generated in the connecting wire, while the helices are approaching the poles of the permanent magnet *a b*, but during the next succeeding half revolution two other induced currents are generated, which, in consequence of the removal of the helices from the poles of the magnet have an opposite direction with respect to the first two currents. If we attach to the helices (fig. 327) suitable arrangements by which they may be put in rapid rotation, we shall have a dynamo-electric machine capable of producing a series of induced currents in quick succession which will decompose water, magnetize soft iron, and produce all the other effects of the current of a voltaic battery.

FARADAY'S MACHINE.

The first dynamo-electric machine was constructed by Faraday. Barlow had shown that a copper disk, placed between the poles of a magnet (fig. 329), will rotate in the magnetic field when traversed by an electric current from its axis to its periphery, where there is a sliding contact. Faraday, in 1831, showed that by mechanically rotating a similar disk, between the poles of a magnet, continuous currents were obtained. These he drew off by collecting springs of copper or lead, one of which touched the axis (fig. 330) while the other pressed against the amalgamated periphery. As early as 1826, Faraday had conceived the idea that when an armature was removed forcibly from a permanent magnet, the expenditure of force thus made should give rise to a current in the wire surrounding the armature; but it took

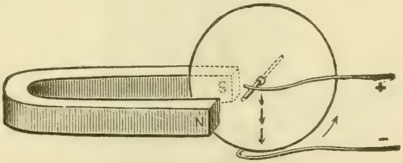

Fig. 329.

him five years to practically develop it. When Faraday saw the spark produced by this machine, and was able to show it to the members of the Royal Institution, he said: "Although this spark is very small, so that you can hardly perceive it, others will follow who will make this power available for very important purposes."

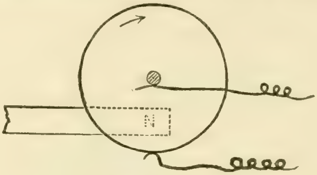

Fig. 330.

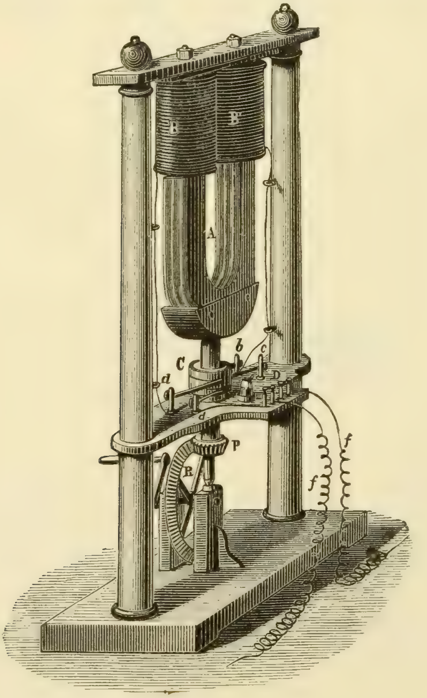

Fig. 331.

Faraday obtained the same result on replacing the ordinary magnet by an electro-magnet, or even a simple helix traversed by a current, having no iron core in the interior; but the current produced by rotating the simple copper disk in the magnetic field had very little intensity. To obtain induced currents of any strength they must be developed in conductors of some length, in order that the resistance of the exterior circuit shall not greatly exceed that of the armature, and thus enable the current to traverse it instead of retrograding by the conductor in which the induction occurs. The first artificer who constructed a machine on this principle was Pixii.

PIXII'S MACHINE.

Pixii's machine (fig. 331) was constructed the year following the discovery of Faraday. B B′ are coils of insulated silk wire 3,000 feet in length, wound round a massive soft iron core and fixed to a horizontal cross-piece; below is a compound permanent magnet A, movable about a vertical axis to which a rapid rotation may be communicated by means of the handle attached to the bevel gearing wheels R and P. Every time the poles of the magnet A arrived under the armature of the electro-magnets B B′, and quitted it, there were induced currents developed in the wires *f f*. This ingenious machine, which was rather inconvenient in actual use, was soon replaced by the much more portable apparatus of Saxton, in which the mechanical arrangement is the reverse of that in Pixii's, the magnets being fixed and the coils of wire movable; and it is on this plan that all the subsequent machines have been constructed.

SAXTON'S MACHINE.

Saxton's machine (figs. 332 and 333) consists of a powerful horseshoe magnet, N S, fixed horizontally; an armature of soft iron, having the form of a horseshoe, and each branch of which is surrounded by a wire covered with silk, D D, is set in rotation before the magnetic poles by means of a horizontal axis, N′ N′.

passing between the branches of the magnet, and which is itself moved by means of a wheel E E′. An endless cord, passing at once round the circumference of the wheel and the groove of a pulley fixed on the axis by its centre, serves to communicate motion. The wheel is turned by the crank K. The two branches of the armature, which is fixed transversely to the extremity of the axis, are made to pass successively before the two poles of the magnet. At each passage there is magnetization and demagnetization, and consequently a development in the ambient wire of two induced currents in contrary directions. Hence it follows, that in all there are four currents in each of the two wires for one complete rotation of the horizontal axis. If each current induced in one of the wires is compared with the current induced in the other at the same instant; that is to say, at the instant of magnetization or at the instant of demagnetization, it will be seen that these currents are moving in contrary directions; because the poles of the magnet, to whose influence they are owing, are of a contrary name. In order that they may add to, instead of neutralize each other, the two ends of each of the wires whence the current seems to come out must be connected together, and also the two ends at which it seems at the same time to enter. These four ends, thus united two and two, present now only two extremities, which are like species of poles, and which are to be united by the body destined to be placed in the route of the induced currents. One of the extremities of one

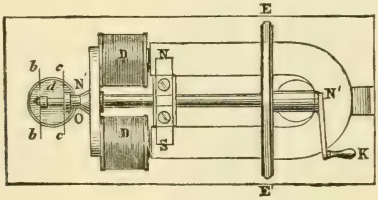

Fig. 332.

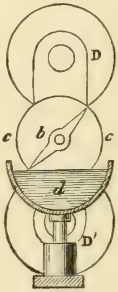

Fig. 333.

wire may also be united with the corresponding extremity of the other; so that the two wires shall form but a single one, traversed entirely by each of the induced currents developed in both wires. It is necessary that, in the same instant, the two currents simultaneously induced should have the same direction; which is obtained by properly selecting the two extremities that are put in communication, and which are called, in order to express this idea, correspondent. The two other extremities, that are not united together, form in this case the two poles. The difference presented by these two arrangements consists in that in the former, there are two parallel circuits, the effects of which are added together; and that, in the latter, there is but a single circuit of a double length, which propagates a double current of induction. The second circuit is evidently much less a conductor than the first, since it is composed of a single wire of a double length, instead of two wires of half the length; on which account it is preferable, when the currents of induction are in tended to traverse imperfect conductors; the first is preferable in cases where the bodies that are placed in the course of these currents have a good conducting power. It is easy with the same machine, to connect together the ends of the two wires according to either mode, and thus to be able, with the same apparatus, to obtain the various effects that would require two, one of which would be with a short and thick wire, and the other with a long and thin one. In order to establish communication between the two extremities of the wires or poles, one is made to terminate in a stem fixed on the prolongation of the axis N′ N′, and which moves with it, and the other in a small, vertical disk of copper, *c c*, fixed by its centre to the same stem, which traverses it, but from which it is insulated by means of an ivory muff or tube enveloping the stem. The disk constantly plunges by its lower part into a small mercury bath, *d*, which also receives successively the two points of a small brass needle, *b*, adjusted to the extremity of the stem, and communicating metallically with it. The mercury thus establishes every time that, by the effect of the rotary movement, one of the points plunges into it, a metallic communication between the two extremities or poles of the inductive wire. If care is taken so to arrange the needle that each of its points plunges into the mercury at the moment when the armature arrives before the poles of the magnet, it follows that the first current of induction occurs at the instant of immersion, and the second at the instant of the emersion of the needle. Thus this immersion and emersion are each accompanied by a spark produced by these two currents, and there are consequently manifested a series of brilliant sparks forming, as it were, a continuous light so long as the rotary movement is given to the armature.

When it is desired to send the series of induced currents through a conductor, the needle *b′*, fixed transversely to the extremity of the axis of rotation, is suppressed, and there is pressed against this extremity, which is hollowed, the point of a small metal stem, firmly attached to one of the pieces of the apparatus, and the other end of which plunges into a cup filled with mercury. This cup, and the mercury into which the small disk *c c* constantly plunges, is placed in communication by means of a conductor, and the latter serves for the passage of the series of induced currents. The bottom of the small cavity at the extremity of the axis is amalgamated, in order that the communication established between the bottom and the point against which it rubs in turning may be entirely metallic, and consequently conducting.

CLARKE'S MACHINE.

In Clarke's apparatus (fig. 334) the magnet is vertical instead of being horizontal, and the apparatus is so arranged as to dispense with the mercury bath. A small spring, constantly pressing upon a metal cylinder put in place of the vertical disk of the Saxton machine, serves to establish the communication ; this cylinder is itself traversed by the axis, from which it is insulated by means of an ivory tube. The axis terminates in a cylinder, serving as a commutator or break piece, and which for this purpose is hollowed out so as to present solutions of continuity upon its surface, or, which is still better, possesses a surface alternately of metal or of wood. It follows that a second spring constantly resting against this piece, is found by the rotation to be in contact sometimes with the metal, at other times with the wood of the surface of the cylinder, which causes it to be sometimes in communication, and at other times not in communication with one of the extremities of the induced wire, whilst the former spring, by pressing against the metallic cylinder which is in place of the disk, and the surface of which is continuous, is always in communication with the other extremity of the wire. By this arrangement induced currents can be obtained, all moving in the same direction. It is sufficient for this to combine the interruptions of the communication between the extremity of the axis and the spring that rests against it, so that they shall occur at the moment when the armature approaches the magnet, or else at the moment when it is receding from it. In the former case, it is the currents induced by the magnetization of the armature that are excluded, and those that occur at the moment of demagnetization are collected. In the latter case it is the reverse.

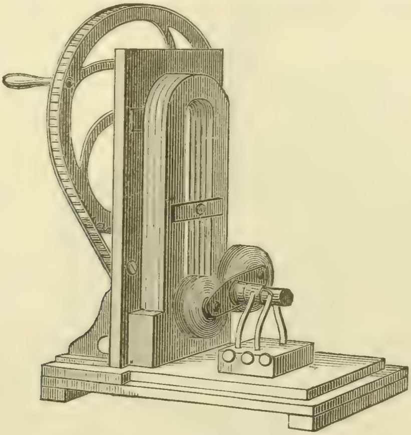

Fig. 334.

Fig. 335 represents an improved form of this machine, constructed by Stohrer, of Leipsic. R R′ are the inductor coils enveloping the soft iron cores, which are connected by an iron yoke. They are so arranged as to be capable of rapid rotation

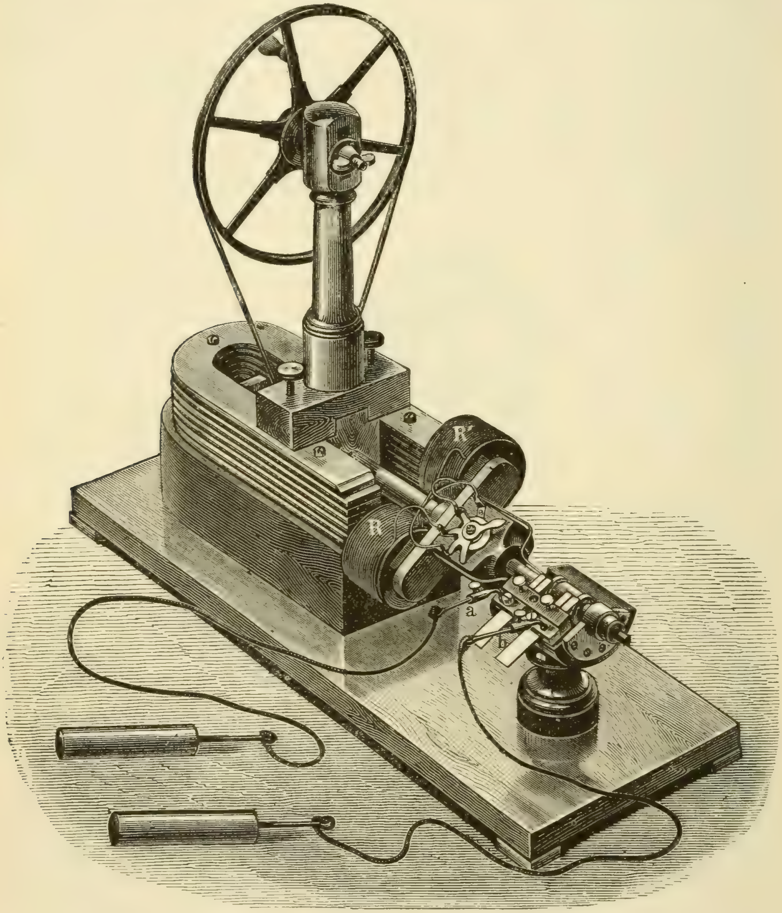

Fig. **335.**

by means of a wheel and an endless cord passing around the circumference of the wheel and the groove of a pulley fixed on a horizontal axis passing between the branches of the magnet. As the coils revolve, they pass as close as possible to the poles of the steel magnet, and each core becomes thereby transformed alternately into a north and a south pole. The terminals *a b* serve to conduct the induced currents from the helices. They are connected directly to the pole-changer, the office of which is to change the currents of opposite direction, which arise during each half revolution, into currents of the same direction, and thus cause the machine to furnish only currents of one and the same polarity. The construction of this device, which is sometimes called a commutator, may be easily comprehended by reference to the sectional view (fig. 336), and the perspective view (fig. 337); *m* is a brass cylinder, upon whose extreme ends two steel half-rings, 2 and 3, are soldered in such a manner that they lie exactly opposite to each other, with the ends slightly projecting. Within this cylinder *m*, but separated from it by a thin insulating bushing of boxwood (in fig. 336 the section of boxwood is represented in black), is inserted another brass cylinder *n n*, which projects beyond the tube in both directions, and carries upon its projecting portions two other steel half-rings, 1 and 4, which correspond with the former pair 3 and 2, as shown in fig. 337. Hence, while rings 2 and 3, and also rings 1 and 4 are in conducting connection with each other, the first pair of rings is insulated from the second by the boxwood. One end of the wire of coil R (fig. 335) is in permanent connection with ring 1, and the end of coil R with ring 2. The entire apparatus above described turns round with the axis. *a* and *b* are two thin steel springs, each of which is attached at one of its ends to the machine, the other end being split, so as to press with considerable elasticity against the

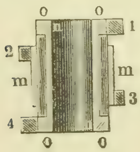

Fig. 336.

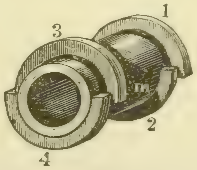

Fig. 337.

rings 1, 2, 3 and 4 as they revolve. The brass supports, to which the springs are attached, are provided with binding screws for the attachment of wires, by which the current may be conducted to any required point. The device which is placed between the coils R R′ and the commutator or pole-changer serves the purpose of combining the several convolutions of the coils in various ways. In one position it unites the ends of both coils so that the turns form one continuous wire; in the other position it connects the front ends of both coils with each other, and the rear ends in like manner. In the former case the current passes through the entire length of the single wire, forming what is called an intensity inductor; in the other case the length of the wire in circuit is reduced to one half, and the cross section is doubled, forming a quantity inductor. Hence, in the first case, the resistance of the coils is four times as much as in the latter case.

WHEATSTONE'S MACHINE.

Fig. 338 is a side elevation of the dynamo-electric machine employed by Wheatstone in 1840, in working his Dial-Electric Telegraph. K K is a fixed permanent horse-shoe magnet, placed horizontally, upon the poles of which are fixed two soft iron cores, with their helices of insulated wire. On a vertical axis passing between these cores is placed a soft iron armature or inductor, J J, which is caused to revolve by means of the pulley

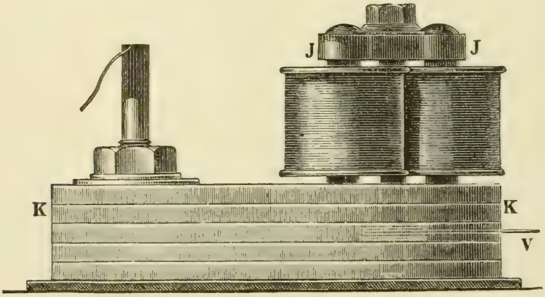

Fig. 338.

and band V, which is connected with a crank, not shown in the drawing. When the armature revolves it induces alternate positive and negative currents in the helices.

STOHRER'S MACHINE.

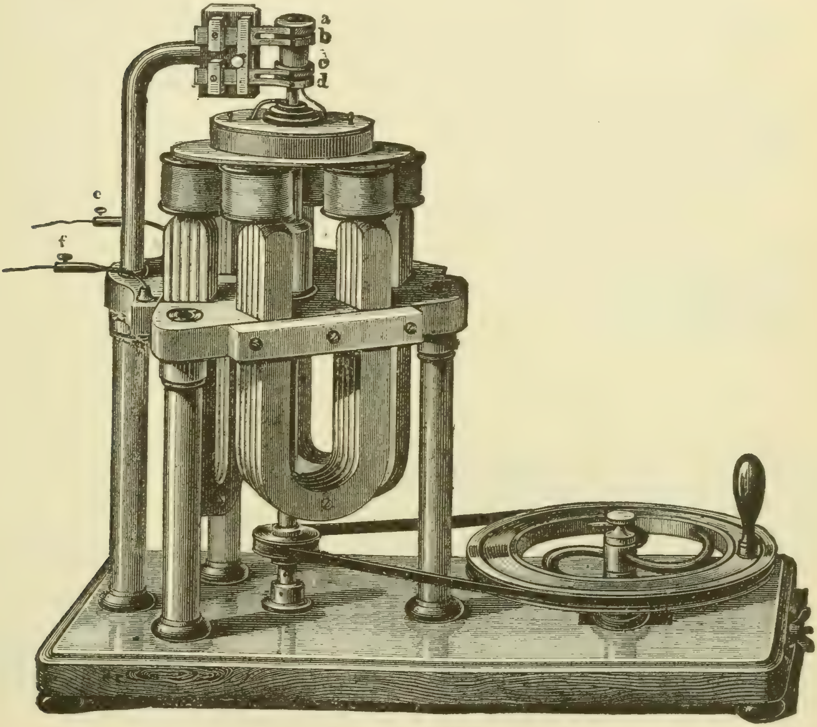

Fig. 339.

In 1844, Stohrer, of Leipzig, devised a dynamo-electric generator, represented in fig. 339, which was likewise employed by him in a machine of a large size. This consists of three upright magnets with six induction coils. The direction of the turns of each coil is necessarily so arranged that the induction currents which arise when the coils are approaching the several magnetic poles are of the same direction. When the coils are moving away from the magnetic poles, we again obtain currents of the same direction, which are, however, in reverse direction to the preceding ones. Hence, the machine, at each complete revolution of the vertical axis which carries the coils, generates twelve currents which are alternately in one direction and the other. Each of these 12 currents consists of six elementary currents, which are generated simultaneously in each coil, and always unite to form a single powerful current.

The larger dynamo-electric machines, constructed for producing the electric light, were used for lighthouses, vessels, etc., and contained from 50 to 60 very powerful systems of magnets, between whose poles the same number of powerful wire coils were made to rotate. The movement of these coils, which were fixed on a common axis, was accomplished by means of a steam engine of several horse power.

SIEMENS' MACHINE.

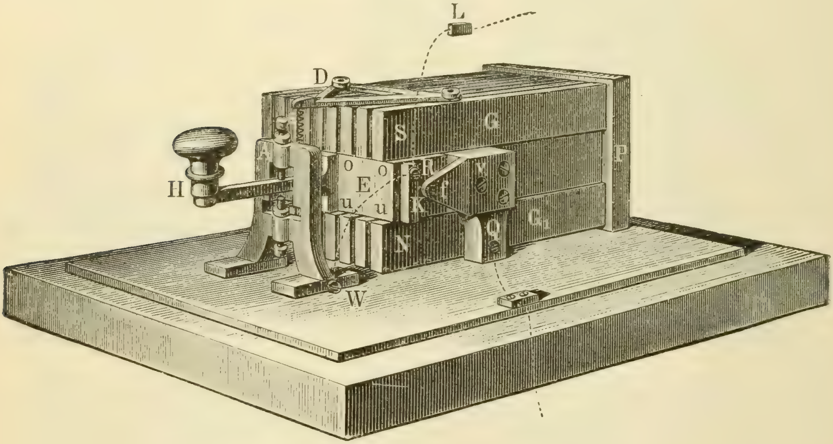

Fig. 340.

Fig. 340 represents a dynamo machine constructed by Siemens in 1854, for working telegraph lines. S and N are two rows of permanent bar magnets; the upper ones with their north ends and the lower ones with their south ends are in contact with a heavy plate, P, of soft iron. The soft iron armature or inductor is as long as the magnet system is wide, and is cut in deep longitudinal grooves, as shown in the cross-section, fig. 341. This is mounted upon two screw points between the poles of the magnet system, and is capable of being oscillated in an angle of a few degrees by means of a handle, **H** (figs. 342 and 343), so that when this is raised the upper edge of the armature *o o* comes in

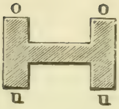

Fig. 341

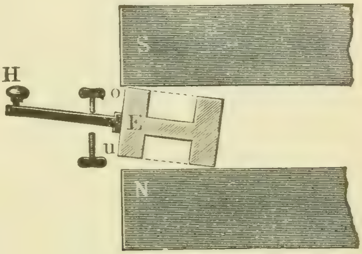

Fig. 342.

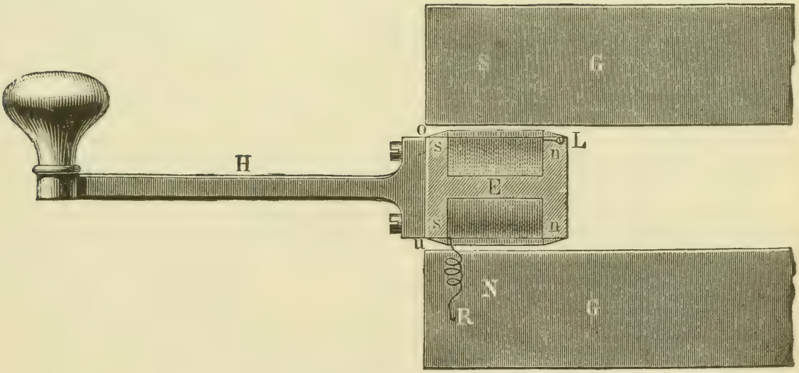

Fig. 343.

contact with the south pole S of the compound magnet system, and when depressed, the lower edge *u u* in like manner comes in contact with the north pole **N**. The play of the lever or handle H is limited by adjustable screws fixed in the frame A. The normal position of the key is that shown in fig. 342, and it is maintained in that position by the spiral spring S, attached to the triangle D (fig. 340). A coil of fine insulated wire is wound longitudinally in the grooves of the armature or inductor **E**, as shown in fig. 344. One end of the coil wire of the inductor is attached to the screw R on the terminal K, which is connected with the line, and the other end of the coil is connected with the metal frame supporting the armature, and through the axis *f* to the upright support Q, from which a wire is carried to the terminal *t*, and thence to the earth. When the handle is depressed a positive magneto-electric current is induced in the coil, which circulates also in the line wire, and a negative current is induced by permitting the key to return to its normal position.

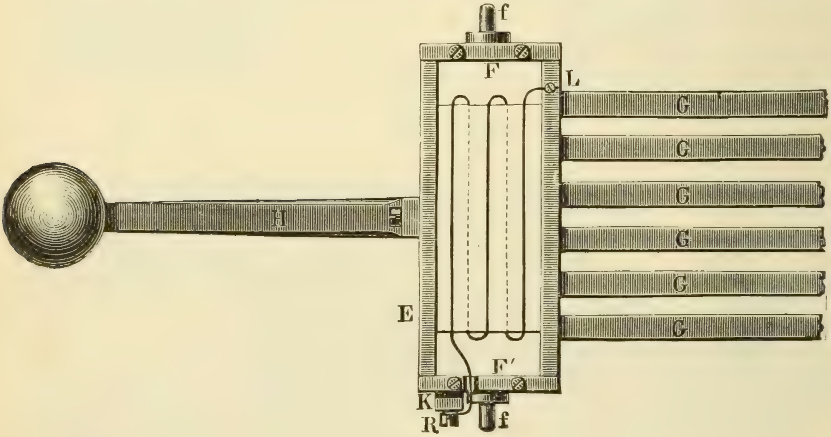

Fig. 344.

HJORTH'S MACHINE.

In October, 1854, Soren Hjorth, of Copenhagen, applied for a patent in England, which was granted in April, 1855, for a dynamo-electric machine, in which the principle of augmenting electric currents by the reaction of electro-magnets upon each other was employed. The general appearance of this machine is shown in fig. 345.

The armatures consist of a series of electro-magnets, A A, forming the periphery of a wheel, by the revolution of which the coils are brought in succession between the poles of the permanent magnet M, and the poles of a series of electro-magnets, E E. The main features of the invention consist in applying the permanent magnet M in connection with the electro-magnets E E,

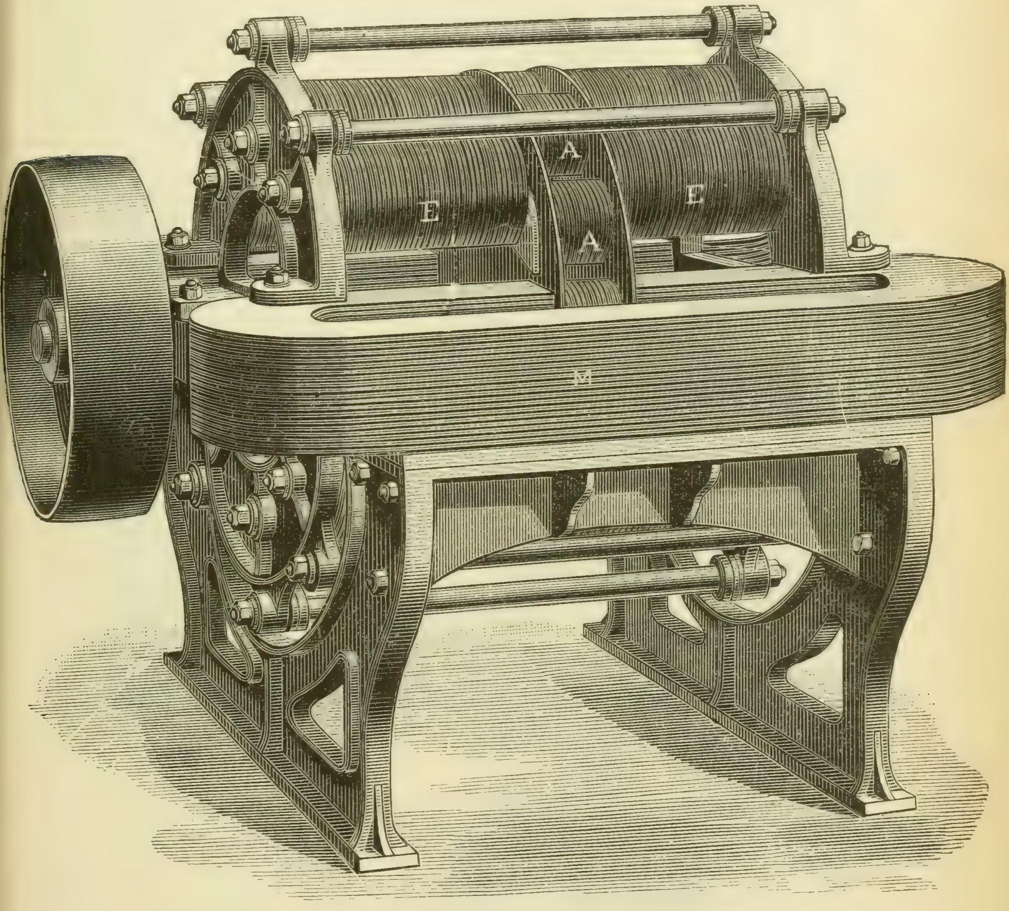

Fig. 345.

in such a manner that the currents induced in the coils of the revolving armatures A A, are allowed to circulate through the coils of the electro-magnets; and as a consequence of this action the more the electro-magnets are excited in this manner, the more will the armatures A A be excited, and the more electricity of course will be induced in the respective coils; and while a mutual and accelerating force is thus produced in this manner between the electro-magnets E E and the armatures A A, an additional or secondary current is at the same time induced in the coils of the electro-magnets by the motion of the armatures, which current, after passing the commutator, flows in the same direction as that of the primary current. The direction of the current induced in the coils of the armatures will of course be reversed according to the change of the respective polarities, and the commutator is therefore applied for the purpose of causing the current to flow constantly in one direction. By the mu-

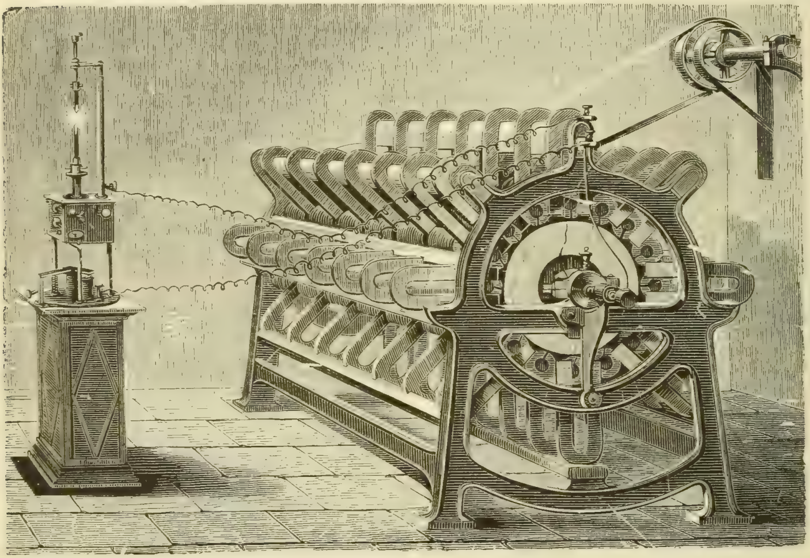

Fig. 346.

tual action between the electro-magnets of the armature and the electro-magnets of the field an accelerating force was obtained, resulting in the production of electricity in greater quantity and power than had ever been obtained from any dynamo-electric generator previously invented. We shall see further on how this great discovery of Hjorth, after remaining apparently unnoticed for a dozen years, was rediscovered by Siemens, Varley and Wheatstone, and resulted in a complete revolution in the practical application of dynamo-electric science.

HOLMES' MACHINE.

Fig. 346 represents the Holmes machine, invented in 1855, and employed by the Alliance Company in lighting some of the coasts of France and England, in which steel magnets were used, between whose poles armatures, furnished with coils of insulated wire, were made to rotate, when, by the inductive action thus produced, alternating currents were set up in the coils, and conveyed to the electric lamps without being changed into a continuous current by means of a commutator.

THE SIEMENS CYLINDRICAL ARMATURE MACHINE.

In 1856 Dr. Werner Siemens, of Berlin, invented an armature which was an advance upon Faraday's original conception, and by which the inductive action was considerably multiplied. In

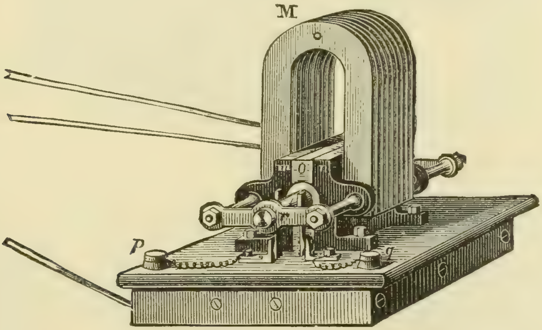

Fig. 347.

Faraday's machine, the armature was separated from the magnet by lifting it away from it. In Siemens armature, the coil is put upon an H piece of iron, and made to rotate in a magnetic

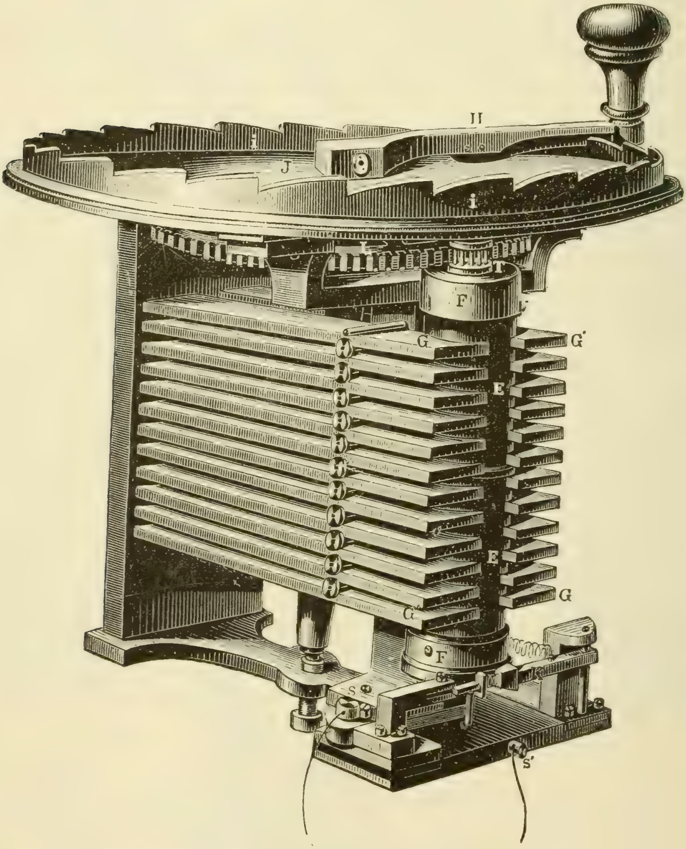

Fig. 348.

field. The magnetic core is made of a cylinder of iron, in which a wide groove is formed longitudinally surrounding the cylinder, and in this the wire of the coil is wound parallel to the axis of the cylinder, and is bound with bands which prevent it from yielding to the influence of centrifugal force when the bobbin rotates. The parts of the iron cylinder left uncovered form the polar ends of the coil. The bobbin revolves on the axis of the cylinder, and in a semi-cylindrical cavity formed in the iron armature *m n*, fitted to the two poles of the inducing magnet M, as shown in fig. 347. The two ends of the wire of the coil terminate in a commutator shown at the end of the axis of the bobbin, on which press two springs connected with the circuit. This armature is more fully shown in figs. 348 to 350.

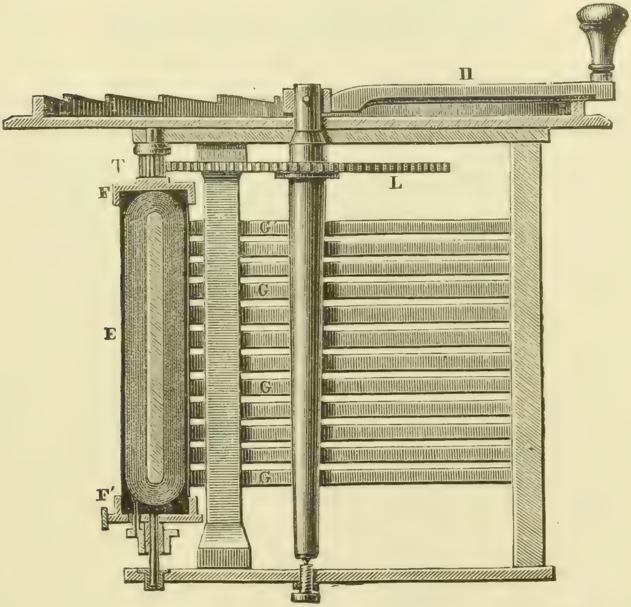

Fig. **349.**

The metal disk J is fixed upon the top of a battery of permanent magnets G G, G′ G′, which are screwed to an upright soft iron plate *n* (fig. 350). Between the poles of this system of permanent magnets is placed a cylinder of soft iron, E, which serves as the keeper or armature of all the magnets. This arrangement, which is the Siemens cylindrical armature, is channelled longitudinally with two deep broad grooves, on opposite sides, best seen in fig. 350. A coil of fine insulated wire is wound longitudinally within these grooves, as seen in fig. 349. The whole armature is supported by brass caps, F F′, in pivots above and below. Above the armature coil the pinion T gears into the toothed wheel L, which turns upon its axis by means of the handle H above the disk J. When the coil is turned half round on its vertical axis, the polarity of the armature is changed, and a dynamo-electric current is induced in the armature coil in one direction, and upon turning it half a revolution further round, so that it takes up its former position, a current in the opposite direction is induced.

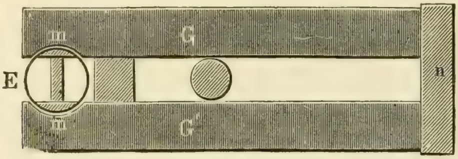

Fig. 350.

PACINOTTI'S RING ARMATURE MACHINE.

Figure 351 represents a machine invented by Dr. Antonio Pacinotti in 1861, in which a rotating armature of annular form and a segmental commutator is employed. The apparatus consists of a cast iron ring, provided with sixteen equal teeth; this ring is supported by four arms of brass, which connect it to the shaft of the machine. Between the teeth small triangular wooden prisms are placed, and into the hollow spaces between the prisms and the teeth coils of silk covered copper wire are fitted. In all the helices the wire is coiled in the same manner, and each of them is formed of nine spirals. Two consecutive coils are separated from each other by an iron tooth of the wheel, and by the small triangular wooden prism. The end of the copper wire of each coil is fastened to the piece of wood which separates the two coils.

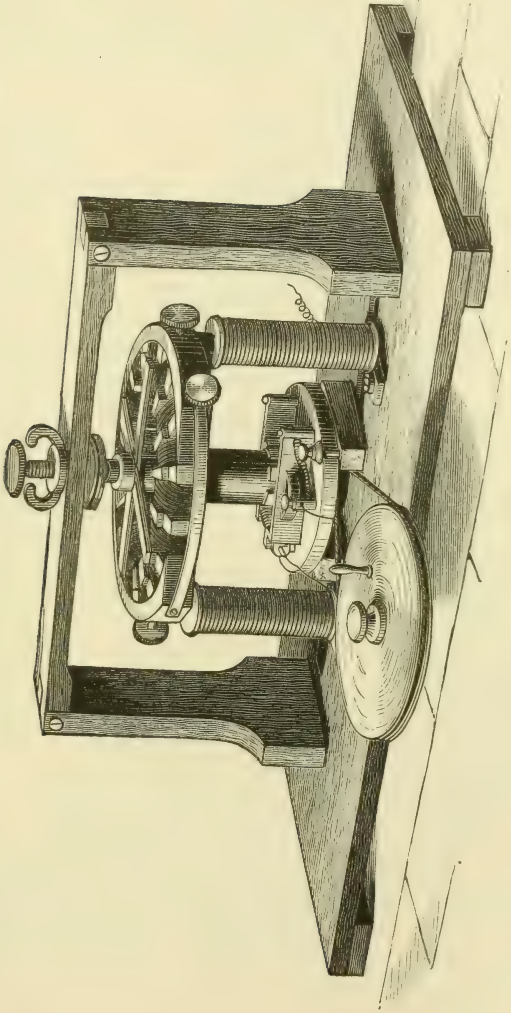

Fig. 351.

All the wires are grouped on the axle which carries the wheel thus constructed. One extremity of these wires forms the end of one coil, and the other the beginning of the following coil, and this is effected by causing them to pass through holes made for this purpose in a wooden collar centred on the same axis, and then attaching them to the commutator, which is likewise mounted on the axis.

This commutator consists of a small wooden cylinder having on its circumference two rows of sockets, into which fit sixteen brass pieces, eight into the upper and eight into the lower sockets, all concentric with the wooden cylinder, over which they slightly protrude, and whose thickness separates one row from the other. Each of these brass pieces is soldered to the two ends of the wire which correspond to the two consecutive coils, so that all the coils communicate with one another, each of them being connected to the following one by a conductor, part of which is formed by one of the brass pieces of the commutator. If, therefore, two of these brass pieces are placed in communication with a battery by means of two metallic rollers, the current on dividing will traverse the helix on either side of the point from whence start the ends of the wires attached to the brass pieces which communicate with the rollers, and the magnetic poles will appear in the iron ring. On these poles act the poles of a fixed electro-magnet, which determines the rotation of the transversal electro-magnet. When it is in motion, the poles are always reproduced in the fixed positions which correspond to the communications with the battery.

WILDE'S SEPARATELY EXCITED MACHINE.

Mr. Wilde, of Manchester, in 1863, constructed a machine in which he substituted in place of steel magnets, electro-magnets excited by the current from a separate machine.

As shown in fig. 352, this machine was composed of two parts, of which the upper one was a small machine, with a magnet, M, of 16 plates, between whose poles, *m n*, rotated a Siemens armature. This small machine was placed upon an iron plate, *p*, which served as a connecting piece to the branches A B, of the inducing electro-magnets, formed of iron plates wound round with thick wires, and terminated by the two polar pieces T T, between which the induction coil turned. As the machine made about 2,000 revolutions per minute, great heating

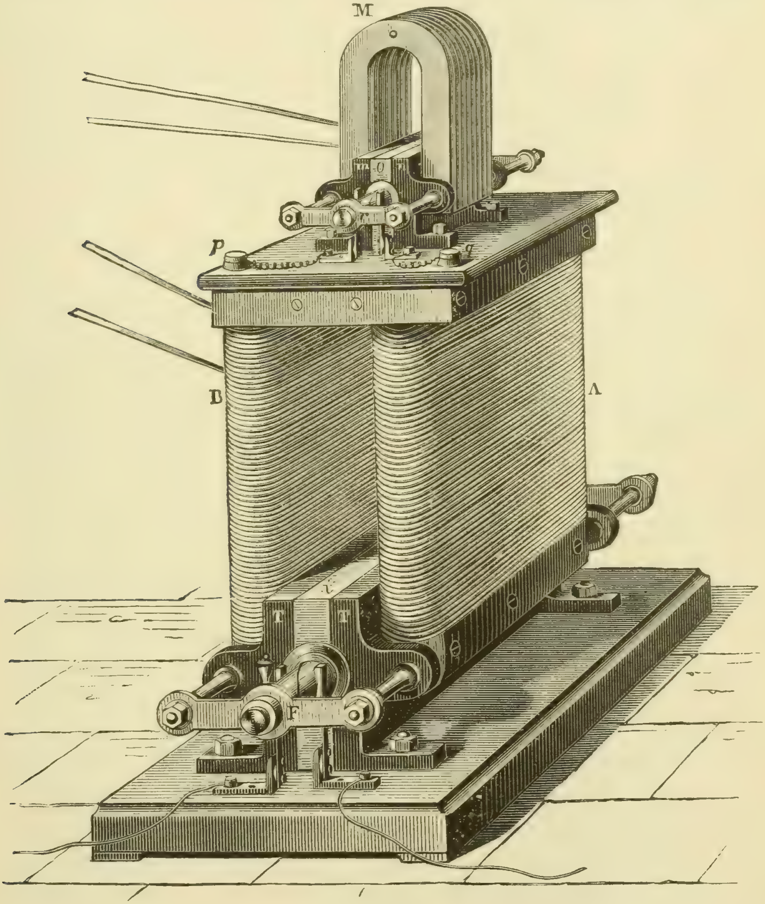

Fig. 352.

was produced, to neutralize which a channel was made in the plate of copper, *i*, which separates the polar pieces T T, through which a current of cold water was made to circulate.

The commutator of the apparatus was placed at the end of the axle of the coil, from which the current was collected by means of two springs pressing against it. The armature rotated also in bearings placed in the cross pieces F, which support it at its extremities.

Under the influence of the movement given to the machine M, the induced current excited in the armature *o* presented itself at the two binding screws *p q*, which were connected with the two ends of the wire of the electro-magnet A B, and the armature rotating between the pole pieces T T, supplied the induced currents required to produce the light.

SELF-EXCITING DYNAMO-ELECTRIC GENERATORS.

All the dynamo-electric machines which had thus far been put into practical use had depended for their action upon the severance of an armature from a permanent magnet, or upon its revolution in a permanently excited magnetic field.

In 1867, another important principle of action was brought prominently into public notice, and at once led to a new departure in the construction of dynamo-electric generators. This principle of action, which was destined to work so great a change in the appliances for transferring mechanical power into electric energy, consists in this, that when the current produced by the severance of an armature surrounded by a conducting wire from the poles of an electro-magnet is sent through the coils of the same magnet that produces the magnetism, a kind of regeneratory action is set up. There must be a magnetic field to commence the action, and in the first experiments, this initial amount of magnetism was produced by means of a small battery connected with a separate coil on the electro-magnets; it was soon found, however, that no such initial excitement was necessary, but that terrestrial magnetism sufficed to induce in the bars of the electro-magnets a magnetic action sufficient to cause a slight current in the coils of the rotary armature, which, in passing through the coils of the field magnets, increased their magnetic tendency; the result was an increased inductive action, and an increased induced current; this again, in passing through the coils of the field magnets, further increased the magnetic intensity, giving rise to increased inductive action, and to a current of increased intensity. The accumulative action thus set up continued to the point of magnetic saturation of the iron cores of the electro-magnets. Up to that point the resistance of the rotary armature rapidly increases, thus causing a direct conversion of mechanical into electrical energy. This is the principle upon which dynamo-electric machines are now generally constructed.

The discovery of this self-exciting principle of action was first publicly communicated by Dr. Werner Siemens, to the Berlin Academy, on the 17th of January, 1867; it was subsequently communicated to the Royal Society, by his brother, Sir William Siemens, on the 4th of February, 1867; and by Sir Charles Wheatstone on the 14th of the same month; both communications being read on the same evening. It was also described by S. Alfred Varley, in an application for an English patent, dated December 24th, 1866, but which was not published until July, 1867.

We have already seen that the principles of this great discovery were embodied in Hjorth's machine, invented in 1854. It is true that Hjorth employed a permanent magnet, in conjunction with the electro-magnet, to produce his magnetic field; but while the presence of the permanent magnet was not necessary to the action of the machine, it did no harm, and, moreover, it is still retained in dynamo-electric machines used in electro-plating, to prevent changes in the polarity of the current; but whether it was retained or omitted, Hjorth's generator accurately illustrated the great principle of the self-exciting dynamo-electric machine, the public announcement of which by Siemens and Wheatstone, a dozen years later, was followed by such remarkable results. The invention did not consist in dispensing with the permanent magnet, although this was an interesting accompaniment of its development for electric lighting; but in the use of electro-magnets in the magnetic field whose coils were so connected with those of the armature that each could mutually produce a regenerating effect upon the other.

This invention, as we have seen, was fully described and illustrated in Hjorth's application for an English patent in 1854, and he is therefore unquestionably entitled to the credit of discovering this great regenerating principle of action, even if he did not rely upon this action alone to excite the field of his dynamo-electric machine.

WHEATSTONE'S SELF-EXCITING MACHINE.

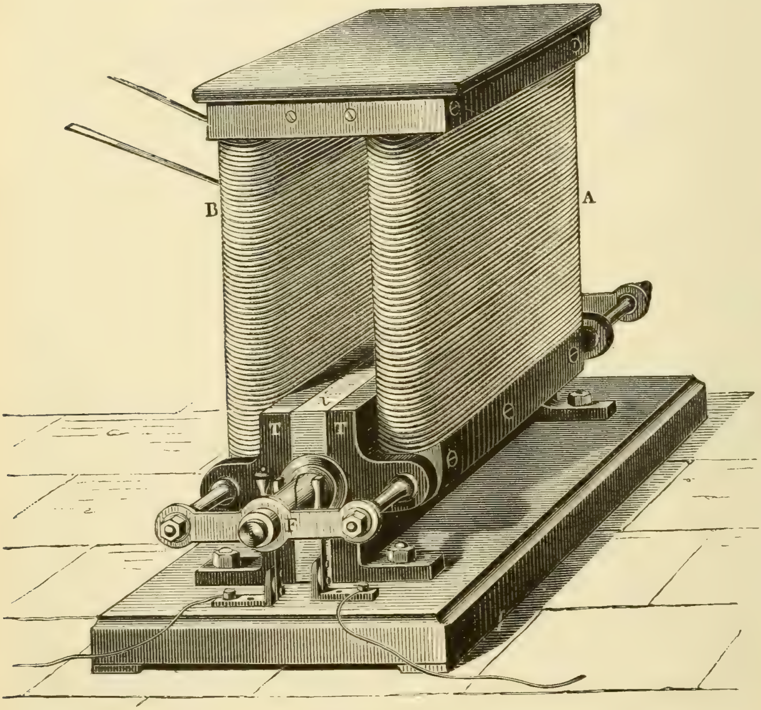

Fig. 353

The first machine embodying the regenerating principle of action, discovered by Hjorth, which was constructed without a permanent magnet, appears to have been made by Mr. A. Stroh, of London, for Sir Charles Wheatstone, in 1866. This machine is represented in fig. 353. It consists of two flat plates of iron, wound round with insulated copper wire, fixed in an upright position, with a Siemens armature rotating between the two pole pieces T T. It is provided with a commutator, placed at the end of the axle of the armature, for the rectification of the currents before their transmission round the electro-magnets.

Fig. 354 shows the arrangement of the circuit in this machine.

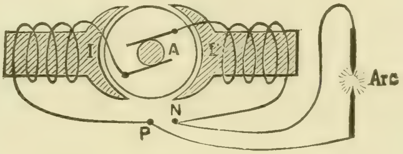

Fig. 354.

A is the Siemens armature, and I I′ are the two coils of the electro-magnet, constituting the field. The continuous current produced by the armature A, after being rectified by the commutator, traverses the coils of the inducing magnets I and I′ at the same time as the arc which it feeds, and therefore the magnetic field depends on the strength of the traversing general current.

LADD'S SEPARATELY EXCITED MACHINE.

Fig. 355 represents a machine constructed by Ladd in 1867, which employs, like the Wilde machine, two Siemens armatures, but differs from the latter principally in not having any permanent magnets to charge the armature which supplies the horizontal field coils B B. Two long flat pieces of soft iron are placed within these coils and are attached to the iron castings or pole pieces MM, NN, which are turned out just large enough for the armatures to fit inside of them and rotate without touching. Thick strips of brass, or other non-magnetic metal, are also placed between the upper and lower castings M and N, to keep them separate from each other, and thus subject the armatures between them to the full force of their inductive action.

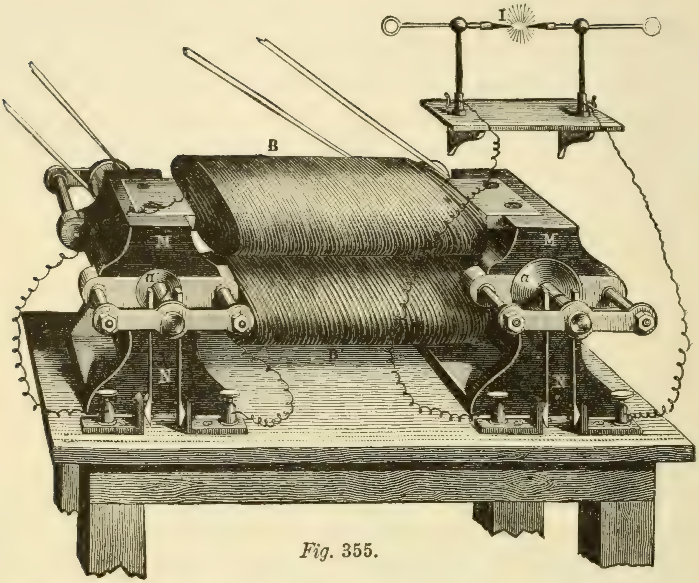

Fig. 355.

The connections of the coils are such as to produce opposite polarities in M and N; and the armature at the left of the machine supplies the field coils, while that at the right furnishes the current for the light. Fig. 356 is a diagram showing the arrangement of the two circuits.

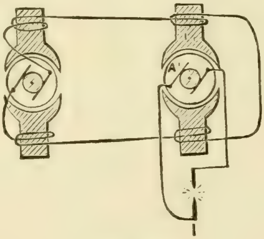

Fig. 356.

GRAMME'S RING ARMATURE MACHINE.

It is a remarkable feature connected with dynamo-electricity, that the second law of thermo-dynamics, viz.: that whenever heat is changed entirely into its equivalent of electricity, a certain amount of heat must descend from a point of high-potential to a point of low potential, is not involved. Theoretically speaking, a certain amount of mechanical force can be converted entirely into electrical force; and electrical force, theoretically speaking, can be so converted into dynamical force. Practically speaking, however, that is not so. There are necessarily losses,

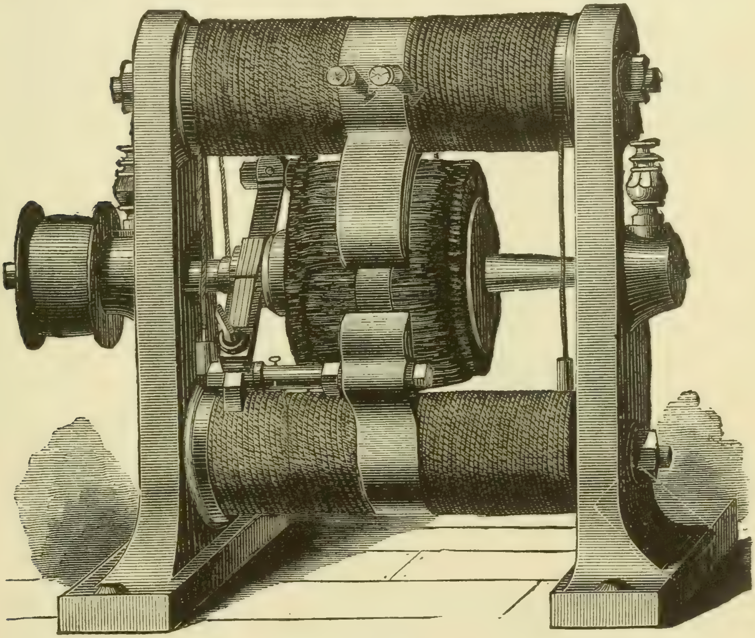

Fig. 357.

and one of these, which is self-evident, is that the current passing through the coils must produce resistance, and electrical resistance, wherever it appears, converts electric energy into heat energy. Again, the iron bars which are magnetized and demagnetized at every half-revolution set up currents in themselves, for it is natural that instead of the current flowing only through the convolutions of the wire, the iron itself being a metal, some current will be set up in it, and this current so set up produces the effect of heating the iron; it simply circulates round and round, forming, as it were, electrical eddies which must be productive of heat. These losses, however, can be diminished almost indefinitely by increasing the size and conductivity of the wires, and as regards the iron, a form of armature has been devised which is best illustrated in the Gramme machine, the original conception of which is due to Dr. Pacinotti. This consists in putting the iron, constituting the core of the armature, in the form of wire coiled round and round a non-conducting body, which is surrounded in its turn by the insulated copper wire forming the coils of the rotating armature. The iron wires being surrounded by a non-conducting material, electric eddies cannot circulate in the direction in which they would occur, namely, transversely to that of the wires, whereas the magnetic poles induced by the field-magnets are free to advance within the iron wires at the rate of the rotative motion imparted to them.

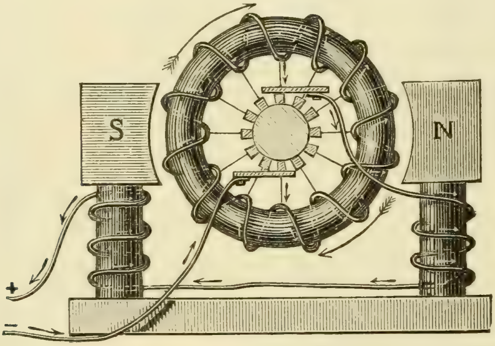

Fig. 358.

Fig. 357 is a general view of the Gramme machine, which consists of two cylindrical electro-magnets with their combined poles extended by pieces of iron of such shape as nearly to envelop the armature which rotates between them. Fig. 358 is a skeleton diagram of the working parts of the machine in which the ring armature rotates between the poles S and N of a horseshoe electro-magnet with vertical limbs. The commutator, a general view of which is shown in fig. 359, consists of a number of separate bars of copper fixed round the periphery of the axes, while above and below are the contact brushes which touch the highest and lowest pieces of the commutator respectively. In the diagram, fig. 358, the ring is inwrapped by a continuous helix of twelve turns; each one of which is connected with one of the twelve copper strips of the commutator. The armature is supposed to rotate in the same direction as the hands of a clock, and therefore the separate turns or coils in the upper half of the ring are moving from S toward N, while those of the lower half are moving from N toward S. Direct currents will be generated in all the coils that are on the right-hand of the diameter, and inverse currents in all the coils on the left. The small arrows show the directions of these currents. By following out the various turns of the spiral it will be seen that all the separate currents induced in the individual turns of the spiral on the left of the vertical diameter are in the same direction along the wire, and, therefore, all help one another in producing a strong current, though the electro-motive force in each may not be equal. The strongest force is in the coils that are passing closest to the

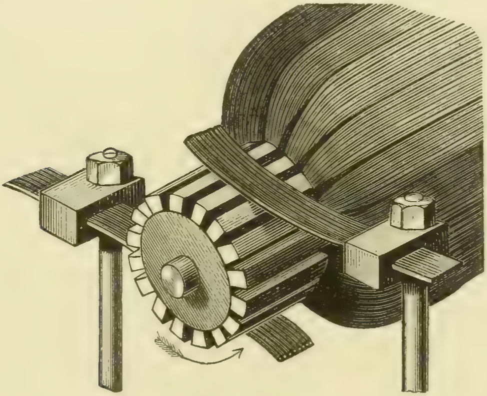

Fig. 359.

poles. In the right-hand half of the spiral the individual currents are all flowing in the opposite direction. Up each side of the ring armature, therefore, there is a strong current flowing, drawing electricity from the lowest and urging it toward the highest point. As the bars of the commutator are separate, and each is insulated from the others and from the axis, no electricity can flow into any of them, except the two bars that occupy the highest and lowest points, which touch the contact brushes communicating with the external circuit. By this means the electricity that passes up both right and left of the ring armature can flow into the upper contact brush and thence into the leading wire of the circuit, which, therefore, has a constant current urged through it. A corresponding action goes on at the lower contact brush; from this point electricity is drawn both to the right and to the left, being supplied by the return wire of the circuit. The current thus furnished is practically continuous; for though the contact is made first with one bar of the commutator and then with another, as fast as they arrive at the vertical diameter, the currents on the two sides of the ring armature will evidently flow toward the point where the contact is made; and there can be no breach in the continuity of the current because one bar of the commutator does not cease to touch the brushes until contact is made with the next, and also because there are

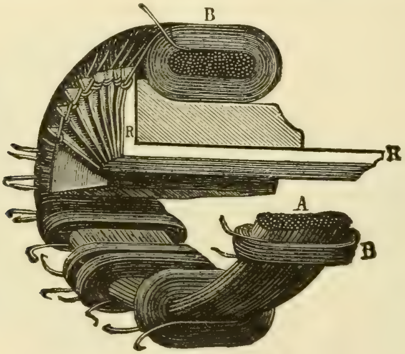

Fig. 360.

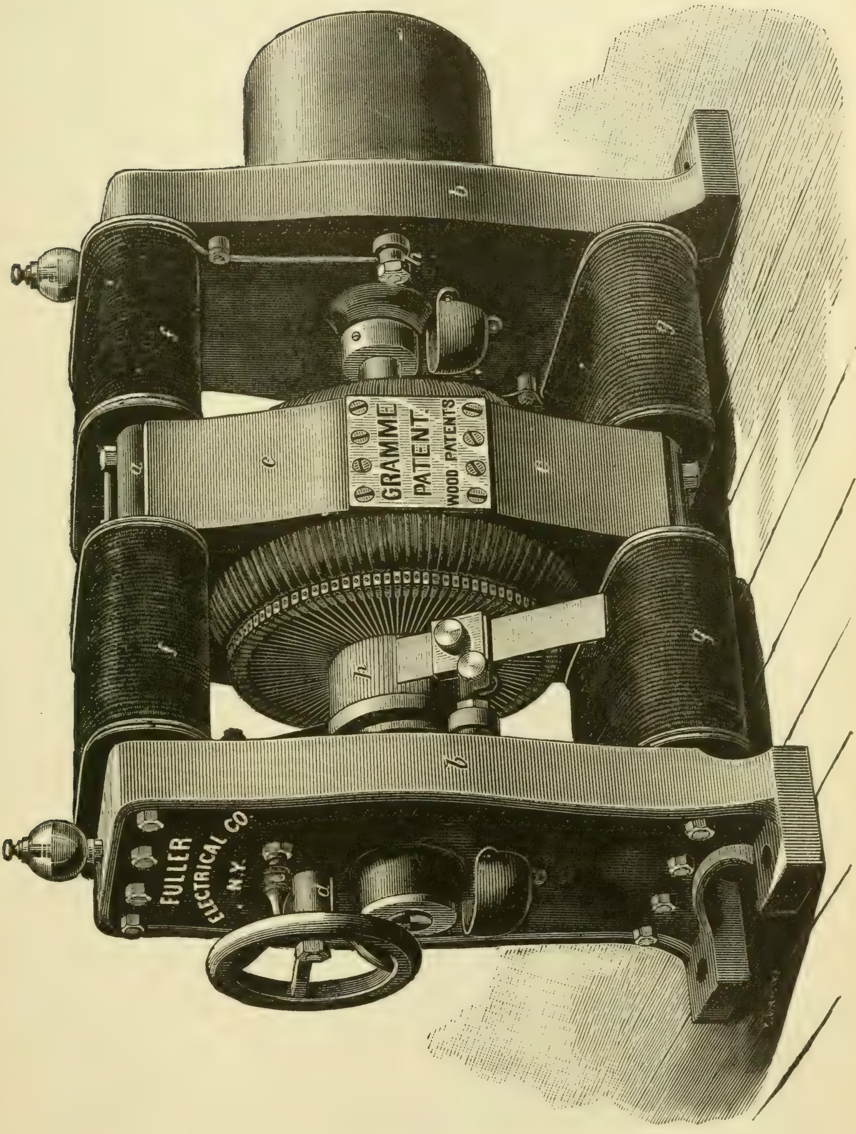
GRAMME PATENT.
WOOD PATENTS
FULLER ELECTRICAL CO. N.Y.
b
b
c
e
f
f
g
g
h
a
d

Fig. 361.

always a certain number of turns of the spiral, on both the right and on the left, in which the elementary currents are being induced.

In the dynamo-electric generators in practical use, the coils of the ring armature are made up of many hundreds of turns (B.B. fig. 360), and these are grouped in sixty sections, the wire at the end of each section being joined to the wire at the beginning of the next, and the junction connected directly with one of the twenty-four bars, R R, of the commutator. The iron ring, A, is composed of a continuous length of iron wire wound into a solid circular hank upon a wooden form, which is removed when the ring is complete. The wire, while it is being coiled, passes through a bath of bitumen, which binds the whole together, and insulates the convolutions of the wire. By this means the cross currents within the core are reduced to a minimum, magnetization is more rapid, and the lines of magnetic force within the ring are maintained parallel in direction to the convolutions of the iron wire, and therefore with the annular axis of the ring.

Fig. 361 represents an improved form of the Gramme machine, designed by Mr. J. J. Wood and manufactured by the Fuller Electrical Company. The field is constructed of rectangular bars, *a*, of wrought iron, with rounded edges, joined at the ends by heavy cast-iron plates, *b b*. The pole pieces, *c c*, are of cast iron, bolted to the rectangular magnetic bars, and secured at their ends by non-magnetic composition plates. The current regulator, *d*, which is on the front end of the machine, is a hand-wheel designed for placing the brushes, which collect the current, in a position around the commutator from the maximum to the minimum point, or vice versa, as required. This wheel is graduated so as to represent the number of lights the machine is designed to operate. A spring latch, *e*, holds the wheel in a position corresponding to the graduation, to represent the different numbers of lights.

The brushes which collect the current are connected with the coils of the field magnets in such a manner that the current from the brush on one side of the commutator passes through the two upper magnet coils, *f f*, and thence to the binding post, *h*; while the current from the brush on the other side of the commutator passes through the under coils, *g g*, and thence to a corresponding binding post on that side of the machine. These binding posts are placed on the end of the machine nearest the pulley, and in such a position that no one could come in contact with

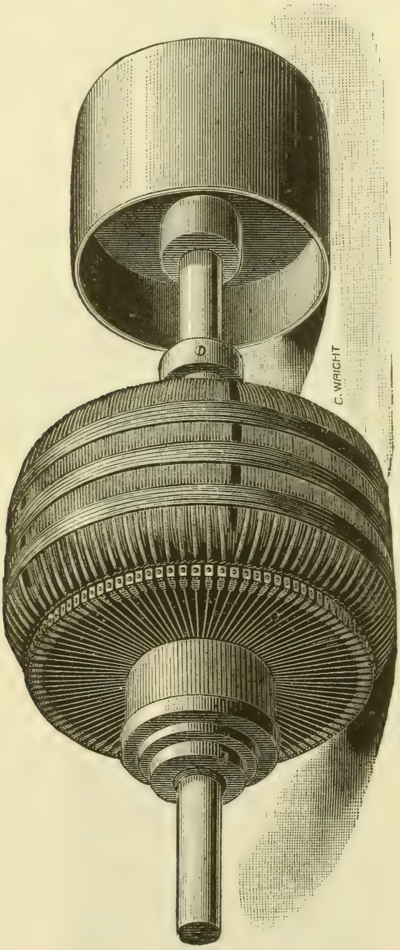

Fig. 362.

both posts at the same time, unless by design, thus removing an element of danger common to many forms of dynamo-electric machines.

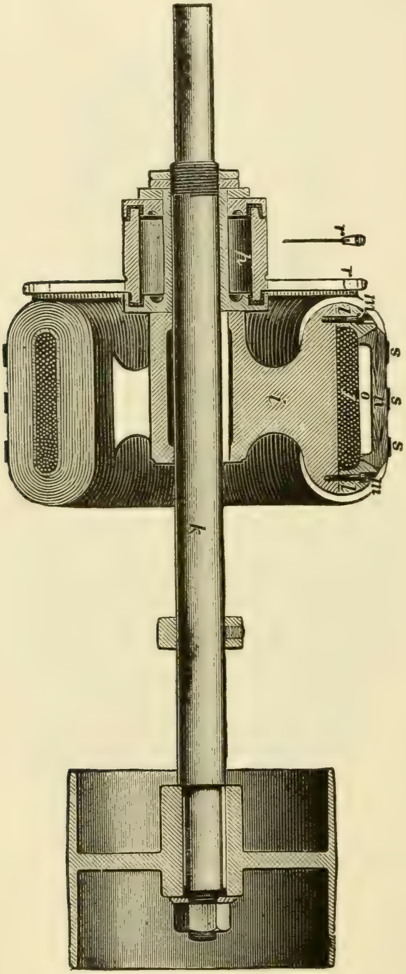

Fig. 363.

Fig. 362 is a perspective view of the armature of the machine, and figures 363 and 364 represent a sectional elevation and end view of the armature, showing its interior construction. In the sectional elevation, *i* represents the spider, which is made of gun metal, and to which the iron ring, *j*, on which the coils of copper wire are wound, is fastened; the whole being firmly keyed to the shaft, *k*. This ring, which is composed of annealed iron wire, and insulated in the process of manufacture, is in direct contact with the gun-metal spider, the object of this being to absorb any heat that may be produced in the ring, *i*. The spider is so constructed as to produce a fan-like motion, causing a strong current of air to circulate through it, and thus dispersing the heat as rapidly as it is produced.

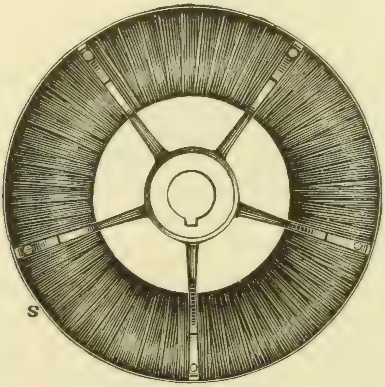

Fig. 364.

The small caps, *l l*, held by the screws, *m m*, hold the iron ring of the armature in position. The wooden strip, *n*, with the space *o*, of which there is one in each arm, prevents the generation of currents in the caps, *l l*, and also serves as a means of balancing the armature. The advantage of this is that the balancing is done exactly at the periphery. The commutator, *p*, is composed of sections of copper insulated from one another, and so constructed that any section can be removed without materially interfering with the remaining sections. This commutator is connected with the armature by a peculiar form of screw clamp, *r r*, and is not soldered.

An important advantage which this armature possesses over the original form designed by Gramme is that it has little or no tendency to become short-circuited or overheated. In the older form of the Gramme armature, the centre was composed of a wooden block, which was driven into place under great pressure, which not only tended to disarrange the wires and injure the insulation, but entirely prevented any circulation of air through them. In the older form, also, the coils after a time became very tightly packed, the hub sometimes became loose, and the proper balance was destroyed; a condition which it is impossible to entirely correct, but which cannot occur in the new form, as there is no strain whatever on the conducting wires.

Another peculiar feature in the construction of this armature, and an improvement over that of older forms, is in the fact that, where the connecting wires are attached to the commutator, they are enlarged to four times their sectional area, which enlargement continues as far back as the band, *s s s*, so that the wires are held rigidly in position, thereby preventing any tendency either to vibrate or break. In machines constructed heretofore for high tension currents, in which small wires are necessarily used in the armature coils, the constant vibrations of the wires at the point of attachment to the commutator rendered them hard and brittle, so that in a short time they would break, and in some instances machines were seriously damaged in consequence. The plan above described effectually prevents such a result.

The improved Gramme generator is made in sizes ranging from those of 300 pounds weight,—generating a current of thirty ampères and sixty volts at a speed of 1,250 revolutions per minute, and producing a light of 6,000 nominal candle-power,—to those of 3,500 pounds weight,—generating a current of ten ampères and 2,500 volts, and producing fifty-five standard lights of 2,000 nominal candle-power each, at a speed of 850 revolutions per minute,—being one of the largest machines in lighting capacity, although not in weight, of any in use.

It is sometimes important to arrange a machine so as to be able to stop its running by shifting the belt, without stopping the power, where it is impracticable to use a loose pulley on the shafting. To serve this purpose, a standard is made to which a loose pulley is attached, as shown in fig. 365. It is designed to be bolted back of the machine, so as to hold the loose pulley concentric with the driving pulley of the machine. It is fitted with a stationary oil-cup, so arranged as to allow the bearing of the loose pulley to be oiled while in motion.

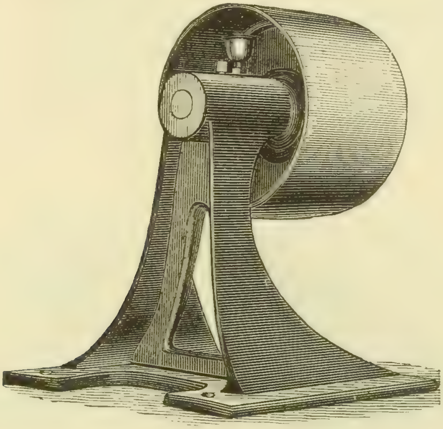

Fig. 365.

ALTENECK'S DRUM ARMATURE MACHINE.

The armature of this machine is not constructed entirely according to Dr. Pacinotti's idea, but involves it. This armature, which is now largely used in dynamo-electric machines, is represented in fig. 366. At first sight it appears to be merely a modification of the elongated coil known as the Siemens armature, described on page 546, and is frequently confounded with it. On a wooden bobbin are wound coils of insulated wire in a direction parallel to its longitudinal axis, according to a plan due to F. Von Hefner Alteneck of Berlin, a member of the firm of Siemens Brothers. Each coil of wire thus wound is brought successively into metallic connection with one of the laminæ, through which the current produced within the coil in passing through the magnetic field is conveyed by the commutator and its contact brushes into the wire constituting the outer circuit and the coils of the field magnet. A succession of currents is thus set up, all flowing in the same direction, and constituting in their aggregate a continuous flow. The chief advantage claimed for this arrangement is that the whole of the wire upon the armature, except where it crosses from side to side at the end, is effective; whereas in the Pacinotti ring the copper returns on the inside of the iron ring, so that only one half of its length receives inductive effect in passing through the magnetic field. Fig. 367 is a perspective view of the machine, in which the curved bars surrounding the armature are of soft iron of rectangular section, and are the prolongations of the cores of the powerful electro-magnets, the coils of which are long, flat bobbins wound with insulated wire. The magnet cores are divided longitudinally into several bars having air

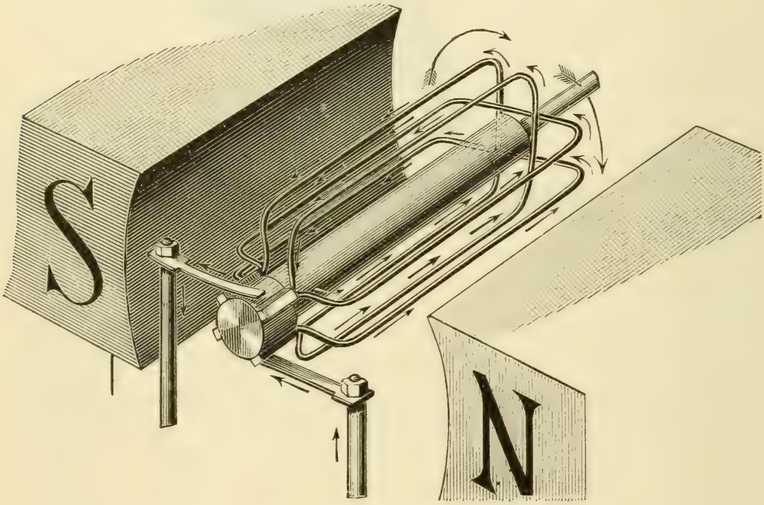

Fig. 366.

spaces between them, the object of which is to prevent cross currents being induced in the magnets, to maintain the lines of magnetic force parallel to the length of the bar, and to permit of a circulation and escape of air between the revolving armature and the magnets, so as to reduce the accumulative heating of the machine. Of the curved portions of the magnetic cores, each surrounds two-sixths of the circumference of the armature, so that two-thirds of it are embraced by the magnets, and the coils of each set of magnets are so wound as to produce a consequent point or pole in the centre of their length, a north pole being produced in the upper set of magnets and a south pole in the lower.

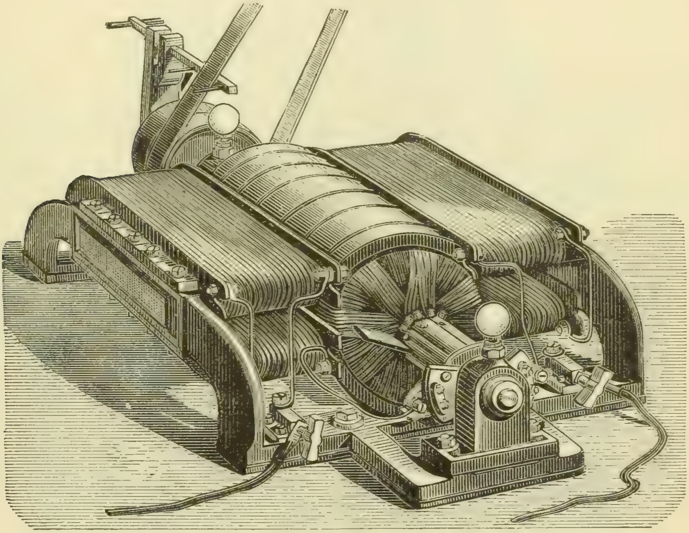

Fig. 367.

Thus a very intense magnetic field is formed within the cylindrical space included between the upper and lower sets of magnet bars, and within this space is revolved at a high velocity the induction cylinder or armature.

The action of the machine is the same as in that of the Hjorth described on page 543. When the armature is revolved, the residual magnetism in the cores of the field magnets induces in the wire on the revolving armature a weak electrical current, which, being led through the commutator to the field coils, increases their magnetic intensity, and consequently that of the magnetic field in which the armature revolves; the effect of this action is to induce in the revolving conductor a stronger current, which, being again transmitted through the coils of the magnets, further augments their power, and these by their reaction induce a still stronger current in the conductors. This mutual action continues until the magnetic limit of the soft iron of the electromagnets is attained. The maximum inductive effect upon each convolution of the rotating coils occurs when it passes through the centre of the two magnetic fields; that is, approximately when it reaches a position perpendicular to the magnet bars; and the minimum effect occurs when the convolution is at right angles to that position; or when it lies parallel to the direction of the magnet bars.

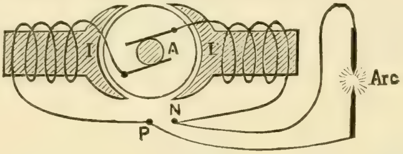

Fig. 368.

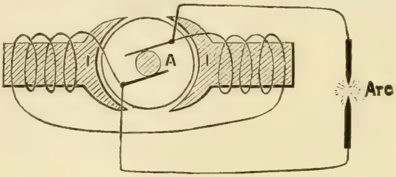

Fig. 369.

Fig. 368 shows the arrangement of the wires in this machine. The continuous current produced by the armature A traverses the two field magnets or inductors I and I′, at the same time that it traverses and feeds the arc which forms a part of the circuit.

Sir Charles Wheatstone, in his notable communication to the Royal Society, of February 14, 1867, also announced another very important discovery, namely, that by making a cross-connection between the circuit passing round the armature and the field a very powerful momentary effect is produced. This cross-connection really severs the current into two parallel circuits, as shown in fig. 369, one portion passing at once out to the electric light, and the other flowing around the bar-magnets and back again to the machine. If this arrangement is applied to a machine wound for a continuous circuit, it will not produce any

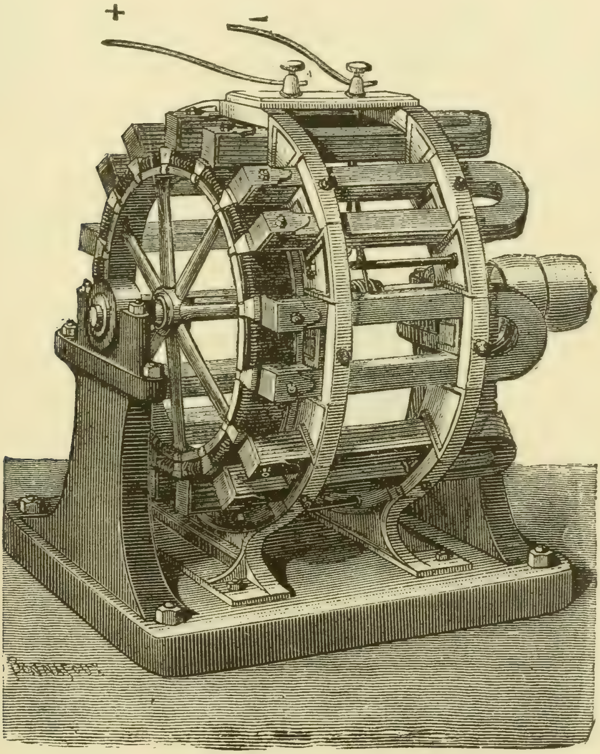

Fig. 370.

useful result; but if it is modified, as suggested by Sir William Siemens, in a communication to the Royal Society in 1880, so that the resistance of the wire on the field magnets is increased a hundredfold, then a machine is obtained capable of very sustained action, and this kind of shunt dynamo-electric machine, as it is called, has been since largely adopted in the production of electric light. The greatest uniformity of current is produced, however, by combining the shunt with a method of winding the coils, whereby the field magnets are furnished with two separate coils, the one of low resistance forming part of the outer circuit, and the other of high resistance, consisting of thin wire, forming the shunt circuit.

DE MERITENS' ALTERNATE CURRENT MACHINE.

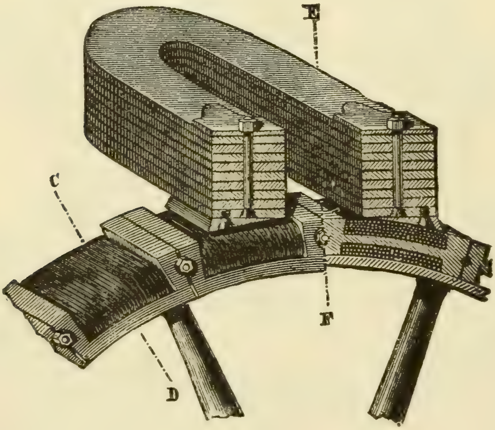

Fig. 371.

The De Meritens machine combines the principle of action of the machines of Holmes and Gramme, and is remarkable for its efficiency in converting motive power into electricity by induction from a magnetic field produced by permanent magnets.

The distinctive feature of the De Meritens machine lies in the construction of its rotating armature, which, like the Gramme armature, is in the form of a ring, and wound in a similar way, but it differs from it in being made up of a number of segments, each constituting a separate arc-shaped electro-magnet with expanded poles, which are joined end to end with a thickness of insulating material between them, so as to form a continuous ring. This ring forms the periphery of a wheel, which is mounted on a horizontal spindle, and is thereby rotated in a vertical plane within a crown of compound horseshoe permanent magnets, and just underneath their polar ends, the distances of which from one another are equal to the lengths of the armature segments, which is the same as the pitch of their poles around the ring: and the armature coils, although all wound in the same direction, are so connected, that while the current sent into the external circuit of the machine is alternating in direction, the currents generated in the several parts of the armature are at any one moment all of the same sign, and therefore in no way tend to neutralize one another.

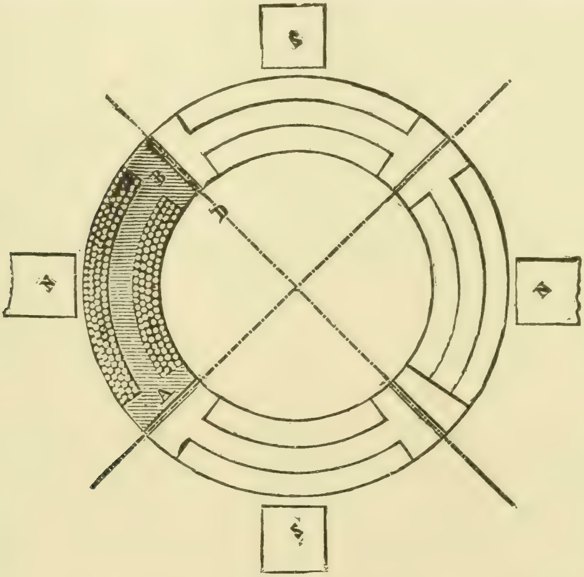

Fig. 372.

The magnetic crown or battery consists of eight horseshoe compound permanent magnets, arranged as shown in fig. 370, and of the construction figured in detail at E, fig. 371. These magnets are rigidly attached to two circular frames of brass firmly bolted to the base-plate, and within the crown so formed the armature revolves on a horizontal spindle, and its electromagnetic inductors are so arranged that their poles in their revolution pass in succession as close as possible to the magnet poles without actually touching them. The cores of the induction helices (see fig. 371) are composed of a large number of thin laminæ punched out of sheet iron $\frac{1}{25}$ of an inch in thickness, and laid flat one upon the other, until a sufficient thickness is obtained. In the larger machines there are fifty plates or laminæ composing each segment of the armature ring. The advantages of this form of construction are twofold: first, the laminated character of the armature cores assists their rapid magnetization and demagnetization, breaking up and otherwise preventing cross currents by which their magnetic capacity is reduced; and second, the building up of the cores by means of superposed plates of the shape of its longitudinal section offers great facilities for construction. While each segment of the ring is thus built up the ring itself is also compound, as shown in fig. 371. The segments, after having been wound with insulated wire, are arranged end to end around a brass wheel, with strips of copper between them, so as to break up the magnetic continuity of the ring, making each segment a complete and separate magnetic inductor, and they are firmly held in their places and together by a bolt passing through each joint, which is tightened by a nut.

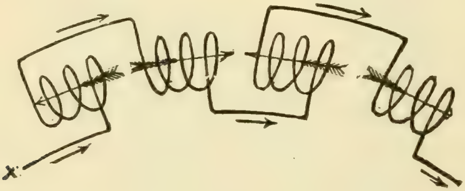

Fig. 373.

The action of the apparatus can best be understood by imagining an extremely simple case of a machine (illustrated in the diagram, fig. 372), having an armature ring built up of only four segments, one of which is shown in section marked A B, and revolving within the magnetic field of two horseshoe magnets, N S, N S, placed with their poles at equal distances around the ring, and so disposed that any point in the ring will, during its revolution, pass them in succession, assuming thereby alternately north and south polarity.

The expansion of the poles, A and B, so as to become flush with the exterior surface of the fully wound coil, beside facilitating the operation of winding, plays a still more important part, and it is to this that a great portion of the efficiency of the machine must be attributed. By this construction, the iron of the cores of the several segments of the ring is brought at its polar extremities into very close approximation to the inducting magnets, N S, in its passage beneath them, and it is for that reason in the best possible condition for being influenced in passing through their magnetic field.

The action of the machine illustrates clearly the principle of that group of phenomena which is known as Lenz's law. Thus, supposing the armature to be rotating in the direction of the hands of a watch, the pole piece, A, approaching the north pole, N, of the permanent magnet, will cause an electric current to be induced in the coil, A B, in a certain direction, while the opposite pole piece, B, will, in receding from the same magnet pole, N, cause the induction of a current in the coil, A B, in the same direction as is produced by the approach of the pole piece, A; the two effects are, therefore, added together, and at the same time the current is still further increased by the convolutions of the coil of the same core passing from left to right through the magnetic field of the magnet, N. As the coils of all the segments are wound in the same direction, the next segment which passes below a south pole at the same moment as the segment A B is passing below a north pole will have induced in its helix a current of electricity in the reverse direction to that developed in A B, which would be opposed to that current, and would, therefore, neutralize it, were it not for the fact that the successive coils are connected together in the manner shown in the diagram, fig. 373, that is to say, the outside end of one helix is connected to the outside end of the coil which is in front of it, while its inside end is connected to the inside end of the coil which is behind it, from which construction it follows, as will be seen in the diagram, that although the currents induced in any two contiguous helices are opposite to one another in direction, the several helices are so connected together that the alternating currents transmitted into the external circuit by each of the coils are all at any one moment in the same direction, either pulling or pushing together. The two ends of the entire circuit of all the electro-magnetic helices are connected respectively to two disk wheels of copper attached to the axis of the machine and revolving with it, but insulated from one another, and upon these wheels stout copper collectors are maintained with a certain frictional pressure, and are connected to the two terminal screws of the machine. By this arrangement all commutators are dispensed with, and the construction of the apparatus is thereby much simplified. By variations in the method of coupling the helices of the armature they may be connected in series, or more or less in parallel circuit, or may be grouped in combinations of the two, and by this means the character of the current generated by the machine may be determined for the work to which it is intended to be applied.

The inventor states, that by this machine as many as three Jablochkoff candles can be maintained burning steadily, with an expenditure of motive power of not more than one horse power, and without appreciably heating its armature or its coils when running at a speed of 700 revolutions per minute.

ALTENECK'S ALTERNATING CURRENT MACHINE.

Fig. 374 represents an alternating current machine, invented by F. Von Hefner Alteneck, and manufactured by Siemens, in which electro-magnets are substituted for permanent magnets, and mere coils of wire for the armatures, rotating through the magnetic fields produced by electro-magnets, which are excited by means of a separate continuous current machine. The principal advantages obtained in suppressing the iron armatures, are, that less weight has to be put into rapid motion, and that less energy is converted into heat by eddies set up within the iron. This machine represents in fact a return to Faraday's original demonstration of the current set up in a conductor passed through a magnetic field; and it is asserted by Sir William Siemens as a fact ascertained by careful tests, that these machines give the highest yield of electrical energy for a given expenditure of mechanical power.

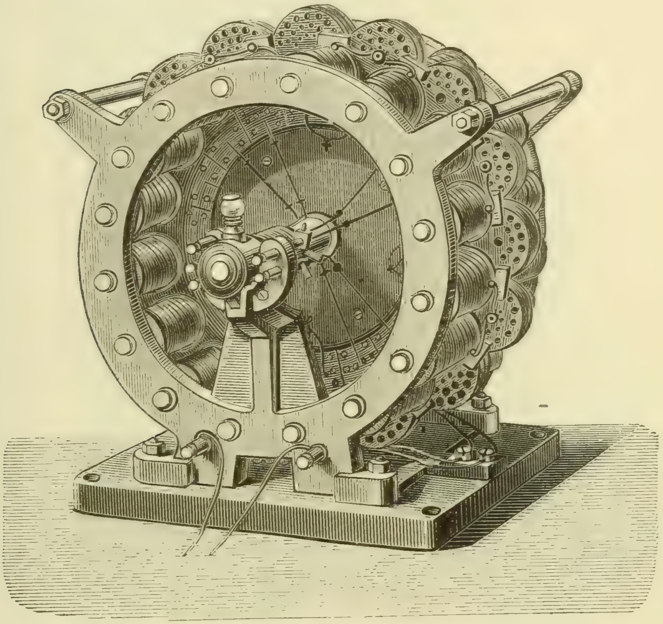

Fig. 374.

Fig. 375 represents the exciting machine attached to its engine. This machine differs mainly from the larger size, shown in fig. 367, by the vertical position of its field magnets, by which the

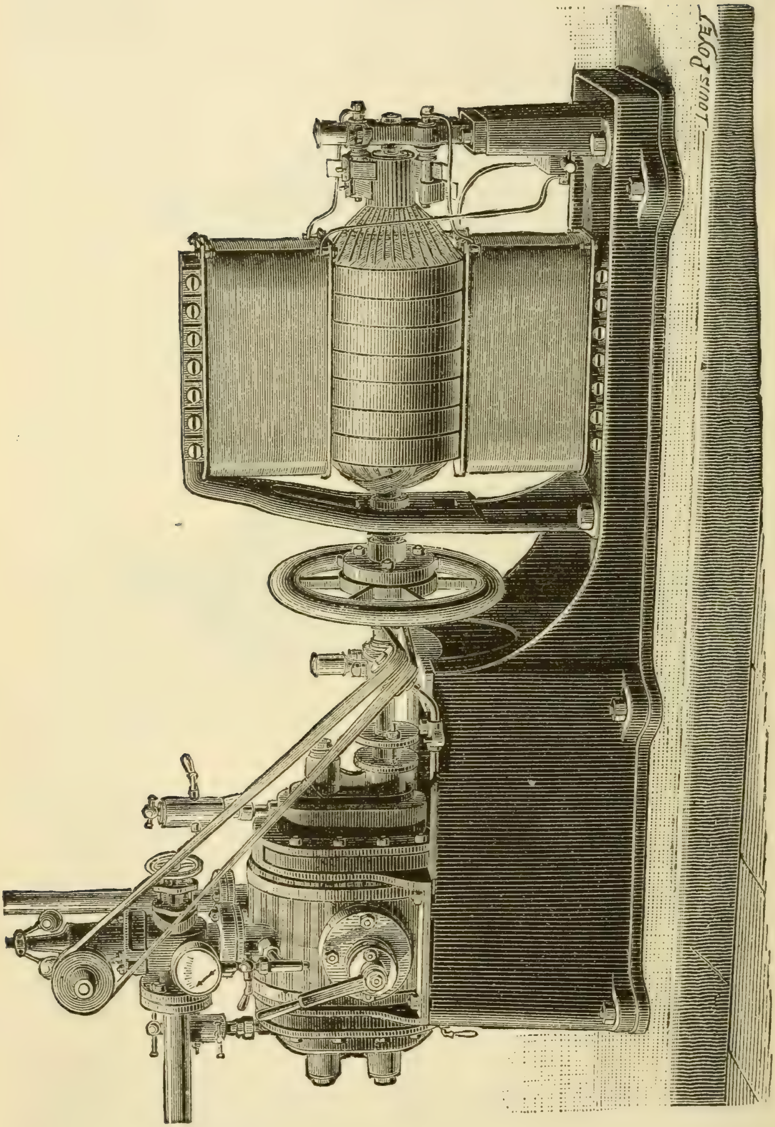

Fig. 375.

induced coil is kept further away from the ground, and by having double collecting brushes for each pole, which enables one metallic part of the collector to be always in contact with one of the brushes when the other meets an insulated part, thus rendering the current more regular.

The alternating machine contains thirty-two electro-magnets, fixed to two cast-iron rings, sixteen on each side of the movable armature. The extremity of the core of each electro-magnet carries a small iron plate, constituting an enlargement of the pole, and thus facilitating induction; these poles are alternately of inverse sense. The armature consists of sixteen helices fixed to a plate, and revolving very rapidly in the circular space between the two series of inductors. The armature coils having

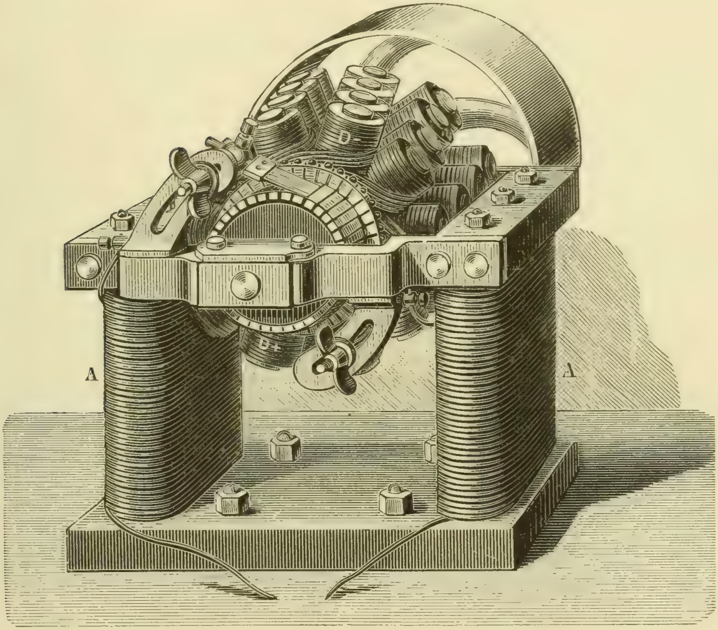

Fig. 376.

no iron core, the current is developed in them merely by the passage of the spiral coils through the magnetic field of the inductors.

The helices are grouped in the most convenient way for obtaining the desired results, and the currents are collected by means of brushes rubbing against the collectors, which are fixed to the extremities of the armature coils.

LONTIN'S CONTINUOUS CURRENT MACHINE.

Lontin's machine, fig. 376, consists of an iron drum, on which are fixed forty iron cores in four rows, placed obliquely. These cores are furnished with magnetizing coils, D D, wound for tension in such a manner that the end of one coil corresponds with the beginning of the next. This system, called by its inventor a magnetic pinion, is mounted on an axle so as to turn between the poles of a powerful electro-magnet, with flattened branches, A A, constituting the inductor, and the coils connected with each other, like the coils of the Gramme machine, are joined by derivation wires with a collector also like that of the Gramme apparatus. This is a self-exciting machine, and the inducer is excited by the entire current. In the most recently constructed form of the machine some improvements have been made. In the first place, the polar extremities of the large inducing electro-magnet have been so arranged that the intensity of the induced current can be diminished at will to any required degree. For this purpose pieces of iron, movable in a kind of groove, have been adapted to the poles, which can be fixed at a greater or less distance from the wires of the magnetic pinion; and the collector is placed apart from the axis of rotation, so that the machine may be covered up and protected. In order to accomplish this, it was necessary to make the communications through the axis of rotation, and the contacts of the collector have been so arranged as to enclose it on the two sides of the axle under a pressure produced by a counterpoise. The rubbing parts themselves are made of an alloy of lead and zinc, and fitted to elastic metallic supports. The continuous current which is produced by this machine is sent into Lontin's alternating current machine, which produces the light.

LONTIN'S ALTERNATING CURRENT MACHINE.

This machine consists of a series of electro-magnets, fixed in the interior of a vertically placed iron crown, having in its centre a rotating electro-magnetic system composed of as many magnetic cores as there are electro-magnets on the crown, as shown in fig. 377, in which the rotating interior electro-magnets represent the inducing, and the fixed electro-magnets the induced system.

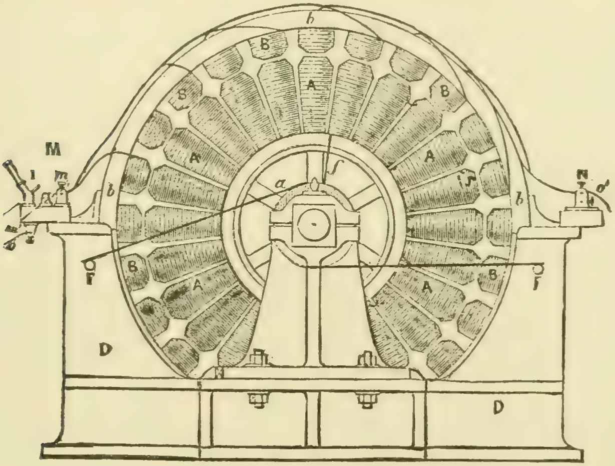

Fig. 377.

The inducing system, which is merely the magnetic pinion of Lontin's generators, described on page 580, is composed of an iron cylinder, to which are riveted a series of iron plates somewhat resembling the teeth of a pinion, and on these the magnetizing coils, A A, are wound for tension. In order that the spires of the coils may not shift under the influence of the centrifugal force, and of the elongation caused by the rather large amount of heat developed, the plates of iron forming the cores are thicker at their free extremities than at their points of connection with the iron cylinder, and this greater thickness plays the part of retaining disks for the spires, which are further maintained in their position by abutting against horizontal iron pieces mounted on two bronze wheels. Finally, the coils are so wound that the polarity of the cores are reversed from one plate to the other, so that the motion of the drum brings magnets of alternately opposite poles before the iron cores of the induced system, which thus receive alternately reversed polarizations. The inducing system is magnetized continuously by the dynamo-electric generator, fig. 376, which may be mounted on the same axle. The induced system is composed of a large stationary iron ring, fitted inside with a series of iron plates fixed transversely, like the teeth of a wheel projecting internally, and surrounded with magnetizing coils, B B B. These coils are connected to each other in couples, so as to form a complete electro-magnetic system, and their free extremities end severally in the commutator M, which enables all the currents they supply to be drawn off separately or collectively by means of the rubbers, *a s*. Inside of this ring revolves the inducer, which is so arranged that the magnetic cores of the two systems pass each other without touching. Thus each of the induced systems is magnetized in opposite directions alternately; for if one of the cores of the inducing system, acting on one of the cores of the induced system, is polarized north, the adjoining core of the induced system will be subjected to the action of a south polarity, and a current will always be produced in the induced system connected with the commutator. When the inducer has advanced, the polarities will have different signs, and a current in the reverse direction will be obtained.

As the action will be simultaneously repeated in all the electro-magnetic systems of the induced bobbins, each of these is able to supply its own action and is independent of the rest, an arrangement which allows of the division of the electric effect. Supposing that each of the induced magnetic systems formed of two bobbins is capable of supplying a current powerful enough to maintain an electric light, the machine represented in fig. 377 would give 12 lights, and if different intensities were desired, it would only be necessary to take away the currents from some of the lights and put them in communication with others. As the induced system is fixed, nothing is easier than to combine the lights in any required manner, and as there are neither rubbers nor revolving contracts, no loss of electricity can occur.

The commutator, M, is so arranged as to act on as many contact plates as the machine supplies currents available for the production of light. The number of these currents depends on the construction of the machine, the one represented in fig. 377, as we have seen, furnishing twelve currents. There are therefore twelve contact plates, and to each of these correspond two binding screws, one of which is connected with the contact itself, while the other communicates with a hand circuit-breaker. The former receives the wire of the corresponding magnetic system, the latter the wire which leads to the electric lamp. Moreover, the various contacts are themselves provided with handles, which connect them two by two and enable an instantaneous union or separation of the partial currents to be made.

GRAMME'S ALTERNATING CURRENT MACHINE.

In this machine the induced apparatus consists of a long iron cylinder fixed horizontally, as shown in fig. 378, and otherwise arranged like the ring in the same inventor's machines. All the small coils, however, *a b c d*, which surround this cylinder, instead of being attached to a collector, are distributed in four separate series, each connected with a particular circuit, so that they successively supply the current to four different circuits. The inducing system is a kind of magnetic pinion formed of eight straight electro-magnets, K K, which move inside of the cylinder, as in the foregoing apparatus, and which, being of contrary polarities, successively supply in each section of the induced coil currents alternately reversed. This inducing system is excited by a Gramme generator like that described on page

557. As in Lontin's alternating machine, there is no commutator: two movable rubbers, in the shape of brushes, press against two distinct circles, and conduct the current from the exciting machine to the movable pinion. Fig. 379 shows the general appearance of the machine and the fly wheel and strap for setting it in motion. The machine is enclosed between two lateral cast-iron mountings, and encased in mahogany, which effectively protect the exterior ring from injury.

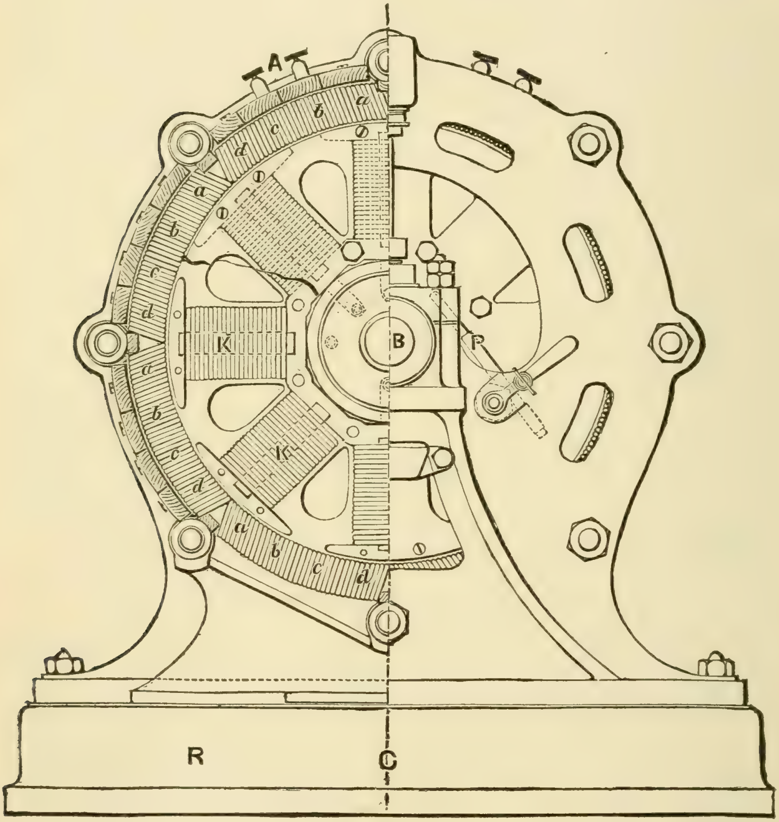

Fig. 378.

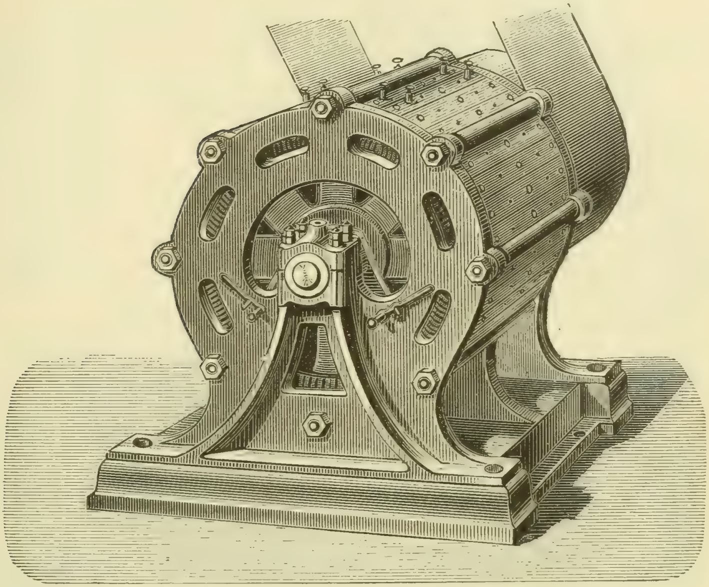

Fig. 379.

In the Alteneck, Lontin and Gramme alternating current systems there is one point of resemblance, viz.: the charging of the field magnets of one or more generators by a current from a special constant current machine. Fig. 380 represents this arrangement, the exciting machine, E, being connected with the field magnets of the four machines, I¹, I², I³, and I⁴, each of which supplies one or more arc lamps.

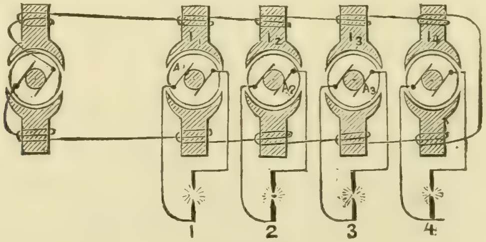

Fig. 380.

NIAUDET'S CONTINUOUS CURRENT MACHINE.

Fig. 381 represents the Niaudet machine. It has a polar armature,—the rotating coils being wound upon radial bars of iron, as upon the arms of electro-magnets—and a Gramme collector. The armature consists of twelve helices, wound with insulated copper wire, and attached by screws to a disk, so as to be parallel with the shaft. This armature revolves between the poles of two permanent horseshoe magnets. Of the two upper poles, one is N and the other S, the corresponding lower poles being consequently S and N respectively. If the two upper poles were both N, and the lower both S, the induction in each half of every core would neutralize the other half, and no current could be obtained, while by arranging them in this manner the inductive effect of each horseshoe magnet is added to that of the other. The coils are connected all around in a continuous series, and at each junction there is a connection to the commutator, as in the Gramme armature. The commutator is made of strips fastened radially to the outer face of the disk, holding the

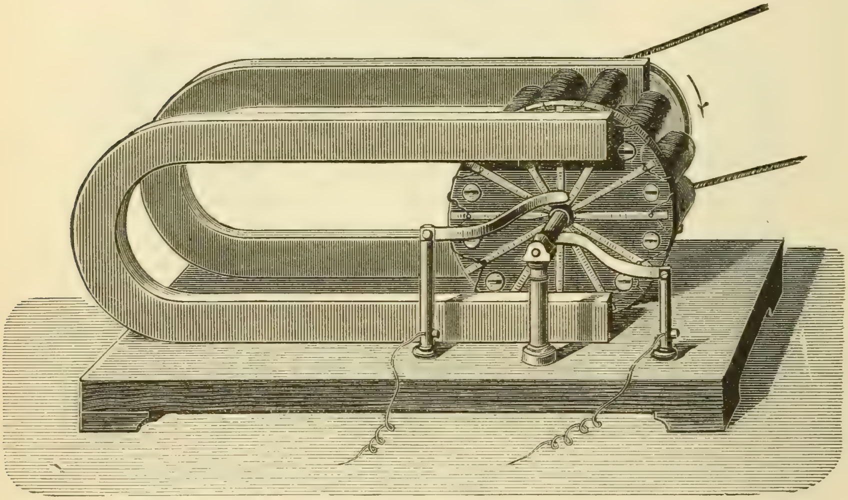

Fig. 381.

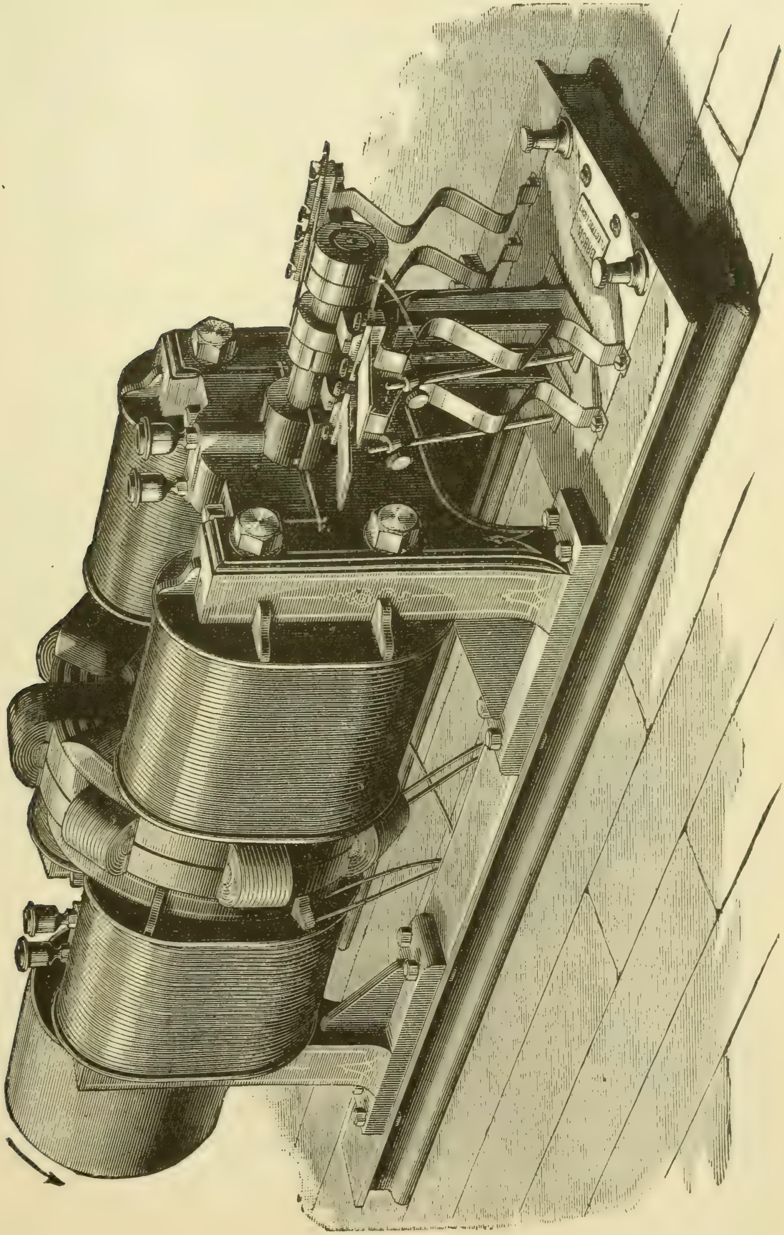

Fig. 382.

cores together, and the collectors are pressed on these at opposite points, the commutation taking place, normally, as each coil prepares to leave one set of poles, as in the Lontin machine. The continuity of the current is due to the fact that the collecting springs; before leaving one of the radial pieces, already touch the next. This machine, though it was at least as good, theoretically, as the Lontin, was never developed industrially, probably because M. Niaudet conceded its inferiority to the Gramme machine.

BRUSH'S CONSTANT CURRENT MACHINE.

Fig. 382 is a general view of the Brush machine. The armature consists of a cast-iron ring, the cross section of which is generally rectangular, but in the direction of its circumference it is alternately wide and narrow, as shown in fig. 383, which represents a portion of the iron ring. The ring is divided into sectors by rectangular grooves; in these the coils of insulated copper wire are wound until the groove is filled, and the flat converging recesses become flush with the face of

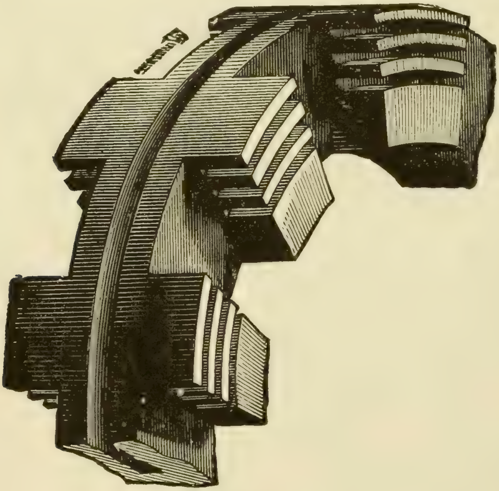

Fig. 383.

the intermediate thicker portions or pole-pieces by which they are separated from one another. Fig. 384 is a cross section of one side of the ring taken through one of these portions. The intermediate thicker portions of the ring are grooved by a series of deep concentric channels, partly to reduce the mass and lessen the weight of the revolving armature, and partly for ventilating the ring and carrying away a portion of the heat generated, but chiefly for the localization and isolation of local currents generated by induction in the iron. For a similar reason the periphery of the ring is deeply grooved; by this means all cross currents are effectually cut off and induction currents are compelled to flow in directions which are not detrimental to the efficiency of the machine. This again increases the area of radiating or cooling surface, and consequently helps to prevent the armature becoming overheated.

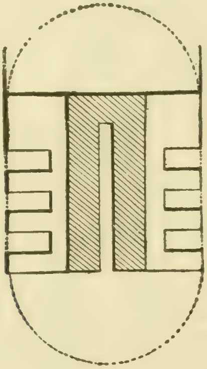

Fig. 384.

In the sixteen-light machine, the armature ring is 20 inches in diameter, and is wound with eight radial coils of cotton-covered copper wire of No. 14 B. W. G., whose middle planes radiate from the axis of rotation, being distributed round the ring at equal angular distances apart. Each coil contains about 900 feet of wire, weighing about twenty pounds. Fig. 385 is a sketch of the armature ring with all its coils wound. The two sides of each groove are parallel to the centre line of the coil. All the coils are wound in the same direction as in the Gramme machine.

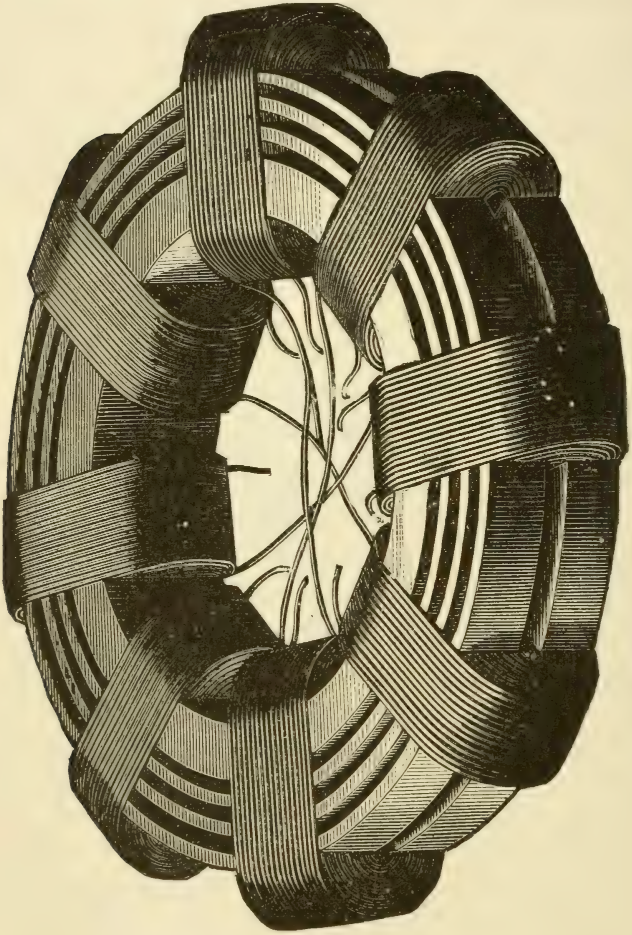

Fig. 385.

Fig. 386 is a diagram showing the distribution of the coils around the ring. The inner end of each of the coils is connected by a wire to the inner end of the corresponding coil, at the opposite end of the same diameter of the ring, and the outer ends of all the coils are brought through the shaft of the machine, and are connected to corresponding portions of the commutator, where the currents are collected by copper brushes.

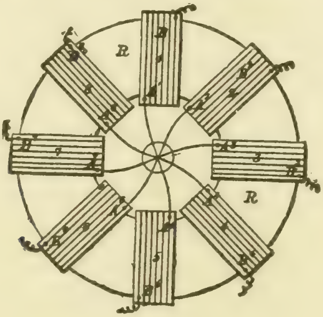

Fig. 386.

The inner end, A¹, of the coil, is connected to A⁵, which is the inner end of the coil 5; A² is connected to A⁶, A³ to A⁷, and so on round the ring, and the outer ends, B¹, etc., are all connected to the commutator by insulated conducting wires. The two free ends of each pair of diametrically opposed coils are, after passing through the shaft of the machine, attached respectively to two diametrically opposite segments of the same commutator, which segments are insulated from one another and from any other pairs of coils. The commutator, which is attached to the driving shaft of the machine, consists of a set of flat cylinders,

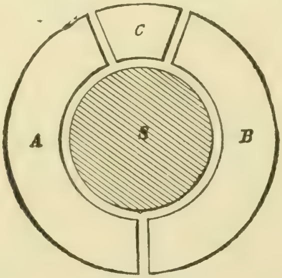

Fig. 387.

of which there are as many on the shaft as there are pairs of coils on the armature, each of which consists of two segments insulated from one another on one side of the shaft by an air space about one-eighth of an inch wide, and on the other by a piece of copper separated from the segments by two smaller air spaces. The arrangement is shown in fig. 387, in which A and B are the two segments connected to corresponding coils on opposite sides of the armature, and attached by an insulating material to the shaft S; C is the copper insulating piece, the object of which is to separate either of the brushes, which press upon the periphery of the commutator, from either of the segments, during the interval occupied by one pair of coils passing through the neutral portion of the magnetic field; this occurs twice in each revolution of the armature. When any pair of bobbins is in this way cut out of the general circuit, their own circuit is open, so that no current can be induced in them. By this arrangement each pair of coils has in each revolution a period of rest equal to one-quarter of a revolution, to which, in a measure, is due the small development of heat in the working of the machine; and it presents also another important element of efficiency in that each pair of bobbins as it passes the neutral portion of the magnetic field, and is therefore incapable of contributing electromotive force to the general current, is itself cut out of the circuit, thereby reducing the resistance by an amount equal to the resistance of two of the bobbins. The method of exciting the field magnets employed in the Brush generator is that discovered by Hjorth, the whole current from the armature being transmitted through the field magnet coils, they forming, with respect to the armature, a portion of the external circuit.

Fig. 388 is a diagram illustrating the connection between the armature coils and the field magnet coils in one position of the armature revolution. Referring to this diagram, M M and M M^1 are the two magnets having their similar poles presented toward one another on opposite sides of the armature coils, A A^1. Thus the coil A is under the influence of a magnetic field produced by the two north poles, N N^1, while at the same time its corresponding coil A¹ is under the influence of the two south poles S S¹. A current is therefore induced in the pair of bobbins A A¹, which is transmitted by wires passing through the shaft S to the commutator C¹, whence it is collected by the brushes B¹ and B⁴, at the same time that the other portions of the commutators (which are in connection with the other working armature coils) are in contact with the brushes B² and B³. At X and Y are the terminals of the external circuit, and to the brushes B¹ and B² are connected the two ends of the field wire. The field magnets are connected together as shown in the figure.

The commutators form a most beautiful piece of apparatus,

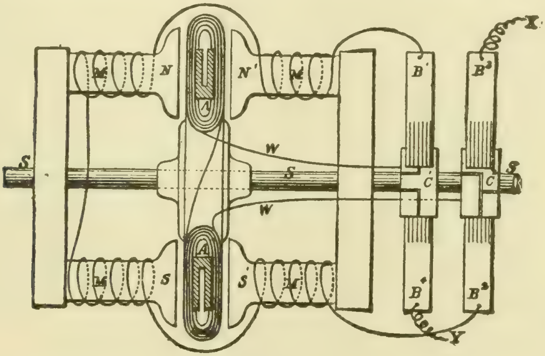

Fig. 388.

and the arrangement by which the position of the collecting brushes can be adjusted so as to place them in contact with the commutators in any desired angular position with respect to the position in the magnetic field occupied by the coils to which the commutators are connected, is exceedingly simple and ingenious By the simplest mechanical means the commutating apparatus collects and distributes the currents from the active armature coils, sending them into the magnet helices and into the line, and cutting out of circuit the armature coils one by one as they pass through the neutral regions between the poles. The whole commutating apparatus is fairly represented on the extreme right of the general view of the machine (fig. 382), and consists of two pairs of rings of the form shown in fig. 387, attached to and revolving with the main shaft. To the cylindrical circumferences of these rings are pressed two pairs of copper collecting brushes, which rub tangentially against the commutator rings, one pair pressing above and the other pair pressing below—a line forming the points of contact being a diameter of the ring. The copper brushes are flat strips of elastic copper about two inches wide, cut at the ends, which press against the rings into eight tongues, so as somewhat to resemble a grainer's comb, and each comb or brush is wide enough to be in contact with two armature rings, and in this way, although two of the coils are insulated twice in each revolution, the main circuit is never interrupted.

For the purpose of adjusting the brushes so as to make contact with the commutators at the most effective angular position with respect to the magnetic field, they are mounted on the opposite ends of two rocking levers, which are capable of oscillating on the driving shaft, and can be fixed in any desired position by means of a set screw, which clamps a stout wire rising from the base of the machine. The currents are conveyed from the brushes by wide strips of thin sheet copper, shown in fig. 282, and in order to allow for the variable distance of the free ends of the brushes from the base of the machine, they are made undulating or wavy, doubling up as the distance is shortened and stretching out when it is increased.

The average resistance of the sixteen-light machines is about eleven ohms, to which the eight coils of the armature contribute about five ohms, that is, .625 ohm each, and the magnet coils about six ohms, or 1.5 ohms for each helix—the resistance of the connections, conductors and contacts within the machine being inconsiderable.

SCHUCKERT'S CONSTANT CURRENT MACHINE.

Fig. 389 is a general view of the Schuckert generator, which is extensively used in Europe for electric lighting purposes. The machine consists of two vertical frames, between which the cores of the field magnets are fixed. These cores are cylindrical except at the centre, where they are widened, the lower core on the upper side and the upper core on the lower side, and a channel is cut partially through them for the armature to revolve in. The armature consists of a ring constructed of thin iron disks,

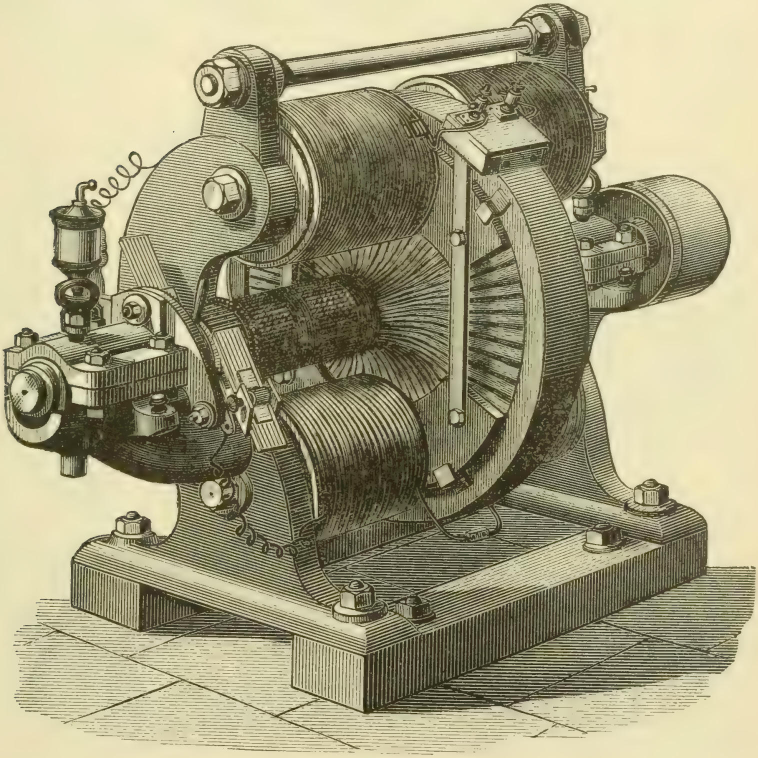

Fig. 389.

insulated from each other and surrounded with copper wire. This ring is nearly enclosed by the semicircular pole pieces of the field magnets, which approach each other within a short distance, near the horizontal axis of the ring, the object of this arrangement being to bring as large a number of the turns of the armature wire as possible within the influence of the magnetic field. The commutator consists of a number of metal segments, insulated from each other, and connected respectively to the sections of the armature coil. The number of these sections varies from ten to one hundred, according to whether the machine is intended for low or high tension, and the end of each section is connected to its corresponding segment by a screw, so as to be easily removed for repair or renewal.

JURGENSEN'S RING ARMATURE MACHINE.

The principal feature of this machine is the introduction of field magnets within the armature for the purpose of utilizing the inner portion of the coils on the ring. The ring consists of a number of thin sections placed side by side, and insulated from each other to prevent the creation of induction currents, by which arrangement very wide rings can be made, the sections being held together by bolts passing through them at small intervals. Around the ring thus formed the wire is coiled to complete the armature.

ARAGO RADIAL DISK GENERATOR.

This machine, originally designed by Prof. Charles A. Seeley, and since improved by the White House Mills, of Hoosac, N. Y., is represented in fig. 390. Two forms are constructed—an electrotyping machine, with a double armature, and a continuous current arc light machine, with a single armature. The special features of the machines consist of the disk form of armature, with its radial winding and the absence of iron within the coils. The magnetic field is composed of a circular range of ten pairs of electro-magnets, the cores of which, on either side of the armature, are cast in one piece, and the connections of the coils are so arranged that the outer ends, as well as the facing poles, are of alternately opposite polarity. The field magnets, which are placed horizontally and are attached to the frame of the machine, are provided with sector shaped pole pieces, which collectively form a disk, and are so placed as to leave a narrow parallel space between them. By this arrangement the magnetic field is confined to the space between the faces of the poles in which the armature rotates, and consequently there is no loss from the forming of external magnetic fields. The armature in the arc light machine, fig. 390, is composed of a series of twelve triangular coils of wire clamped together by hubs and rings of copper. These coils are so wound as to form, when placed in the armature, radial spokes, the adjacent sides of each pair being parallel to each other and close together. The currents developed in the armature are collected by a commutator consist-

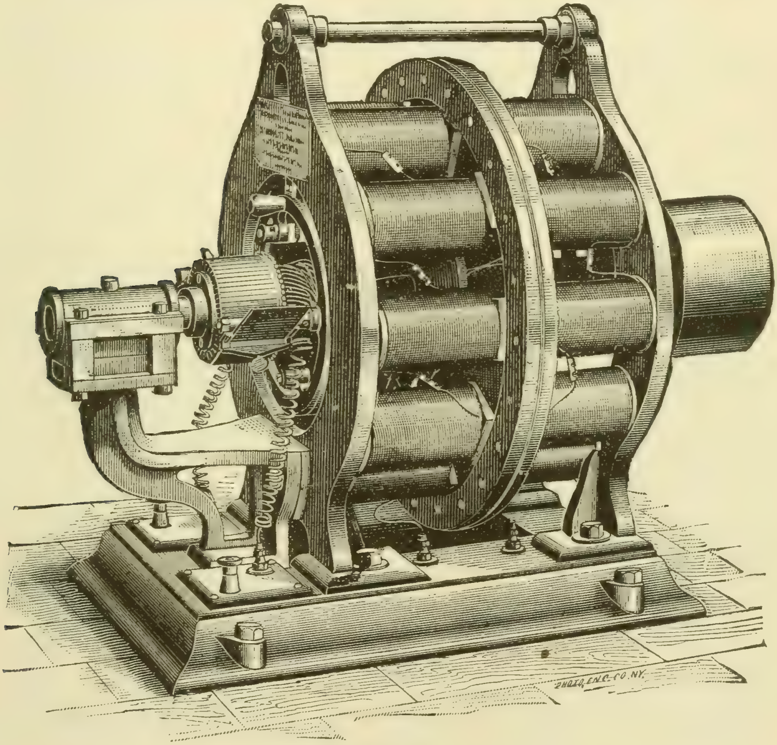
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Fig. 390.

ing of sixty segments. The coils of the armature are connected in closed circuit, and branches lead from the connections between the coils to five equidistant bars of the commutator, constituting an arrangement of connections for rendering the current continuous, similar to that employed in the Von Hefner Alteneck machine. The connection from the armature to the commutator is necessary, because in this arrangement of the coils there are twelve terminal wires to the armature, each of which is positive and negative alternately five times in each revolution, thus changing the polarity of each armature terminal ten times, making a total of one hundred and twenty changes per revolution. Although the positive and negative points change rapidly in the armature, their position with reference to the field is constant, as is shown by the fact that the polarity of the commutator where the brush rests is constant, while the polarity of any one commutator block is constantly changing.

The electrotyping machine is similar in construction to the arc light machine, differing only in the arrangement of the armature and in having two commutators and brush holders instead of one. The armature coils are composed of two layers, one layer being of only half the thickness of the other. Both layers are made of copper ribbon instead of wire. In the thinner layer, which is used to excite the magnets, the arrangement of the armature and commutator connections is the same as in the arc light machine, while the thicker layer is connected to the working circuit in the usual manner, and has no electrical connection with the thinner layer. Both layers are clamped together by one set of hubs and rings, so that to all appearance only one layer is used. As the current from the two sections of the armature can be controlled independently, it is obvious that, by a small movement of the brushes on the commutator connected with the exciting circuit, the power of the field magnets may be increased or decreased without the use of resistance coils, and thereby the current developed in the working coils of the armature regulated as required to suit the work to be done. It is claimed that this form of construction possesses important advantages for electro-plating and charging storage batteries, because there is no liability of reversing the polarity of the current; while for the government of a system of incandescent lighting it is a great improvement over the use of resistance coils. The largest electro-plating machine constructed on this plan is now satisfactorily operating eleven tanks in series, with a consumption of less than fifteen horse power.

BALL'S UNIPOLAR MACHINE.

Fig. 391 presents a general view of Ball's machine, which

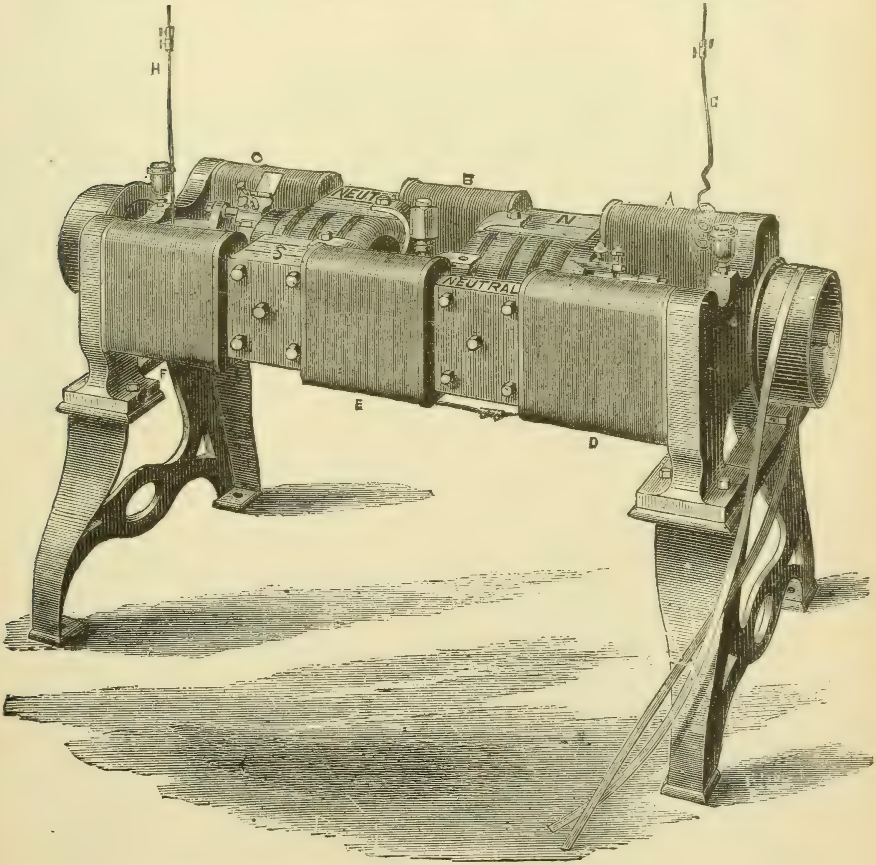


Fig. 391.

consists of a long rectangular frame of soft iron, coiled so as to form the field magnets, and longitudinally supports the axes carrying two ring armatures of the Pacinotti type. The main peculiarity of the machine is that each armature is rotated in the presence of only one magnetic pole, the opposite side of the armature facing a neutral point of the field. The effect of this arrangement, in so far as the field is concerned, appears to be that the rectangular soft iron frame is converted into two long electro-magnets with two poles, only one being presented to each of the rotating armatures instead of four shorter and proportionally weaker electro-magnets having four poles, as in the ordinary way, by which two opposite poles would be presented to each of the armatures.

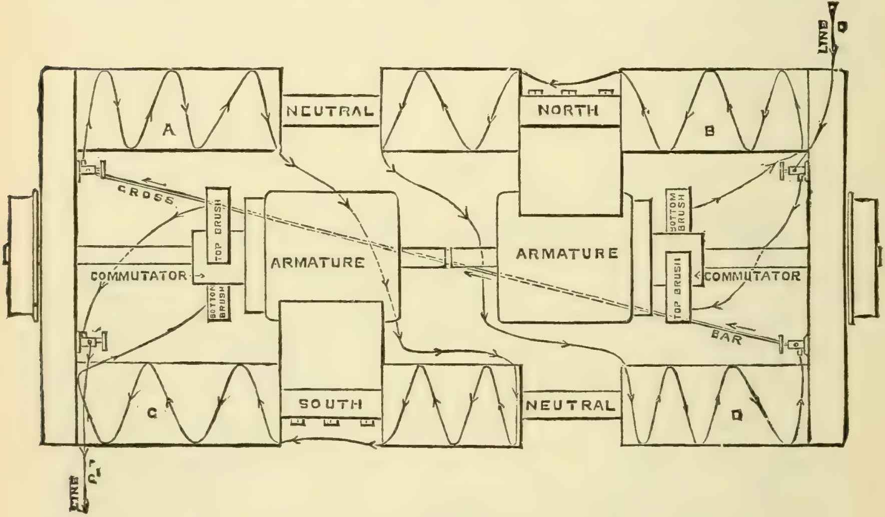


Fig. 392.

Fig. 392 is a diagram showing the peculiar way in which the winding is connected through the commutators and across the machine. Following the negative wire C, the circuit is through the right hand commutator round coil B, thence to central coil, thence back to coil D, then along cross bar below the armatures to coil A, across to central coil next the south pole, and from this to coil C, through left-hand commutator, and on to the positive terminal carrying the lead C.

BURGIN'S RING ARMATURE MACHINE.

Bürgin, struck with the loss of action in the Gramme ring, resulting from the withdrawal of the iron core from the poles of the field magnets, has sought to bring the mass of the iron ring closer to the inductor by making it pass out of the coils at longer or shorter intervals. In order to accomplish this he formed the ring R, fig. 393, of eight separate rings mounted alongside of each other on the same shaft, S, each having for a magnetic core a hexagonal frame, composed of iron wires, on the sides of which are wound the induced coils. These coils are wound in the shape of an ellipsoidal spindle, with a curvature so calculated that the six angular parts of the cores are nearly on a level with the external spires of the several coils, and therefore able to pass the inducing poles at a very small distance. The frames are also so arranged that the angular and uncovered parts of the cores retire from each other, so as to present themselves conformably to a spire of a coil. As a result, the magnetizing actions are produced successively, and the currents due to these actions, as well as to that between the wires of the coils, are always of the same strength in the different phases of each revolution of the ring. The induced coils are, moreover, wound in alternately reversed directions, in order to obtain currents in the same direc-

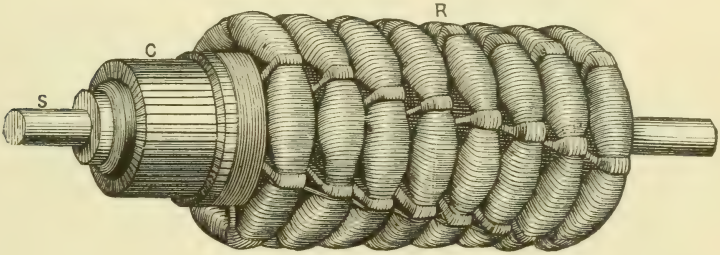


Fig. 393.

tion in each half of the ring, and are joined to the collector C in precisely the same way as in the Gramme, Edison and other continuous current machines. The general appearance of the collector is shown in fig. 393. The field magnets are also arranged in the same manner as those of other self-exciting machines, and the induced current traverses them in its entirety as in those of the other machines made in accordance with Hjorth's regenerating principle. Fig. 354 shows the arrangement of the circuit. These machines have for a given velocity the same luminous power as the ordinary form of the Gramme machine, but they have the advantage of becoming very much less heated.

JABLOCHKOFF'S SPHERICAL MACHINE.

Fig. 394 is a general view of Jablochkoff's machine, which is composed of two bobbins, one fixed upon a horizontal axis in an inclined position, and turning with it; this bobbin is coiled upon a framework of iron, the cheeks of which form two circular poles (north or south), which, by the arrangement of the commutator, change their polarity twice in a revolution; the second bobbin is fixed in a vertical plane more or less inclined in relation to the horizontal axis of the revolving bobbin; it is coiled upon a non-magnetic frame, and the current which traverses it is continuous in direction. The relatively inclined position of the two bobbins has given the apparatus the name of ecliptic, by reason of the analogy which this inclination presents to that of the ecliptic upon the equator.

The apparatus has arrangements for varying the inclination of the two bobbins, so as to determine the best conditions for working; but in the machines designed for commercial purposes the position of the bobbins, once determined, will be fixed and invariable. The mutual action between the movable electro-magnet upon its horizontal axis, which is submitted to the alterations of direction of the current, and the fixed solenoid, in which a continuous current circulates, must result in a continuous and rapid motion of the axis of rotation, with the advantage resulting from the suppression of any magnetic mass in the fixed part.

M. Jablochkoff's invention relates to the construction and arrangement both of electro-dynamic and dynamo-electric machines in a simple form; or, in other words, his invention may be applied either in electro-dynamic machines—converting electricity into motive power—or in dynamo-electric machines—converting motive power into electricity; and the following sketches illustrate some of the various arrangements proposed by the inventor: Fig. 395 is a diagram showing a simple form of machine; A bobbin, A, having cheeks or flanges, A B, of soft iron, and wound with a coil of insulated wire, is fixed obliquely on an

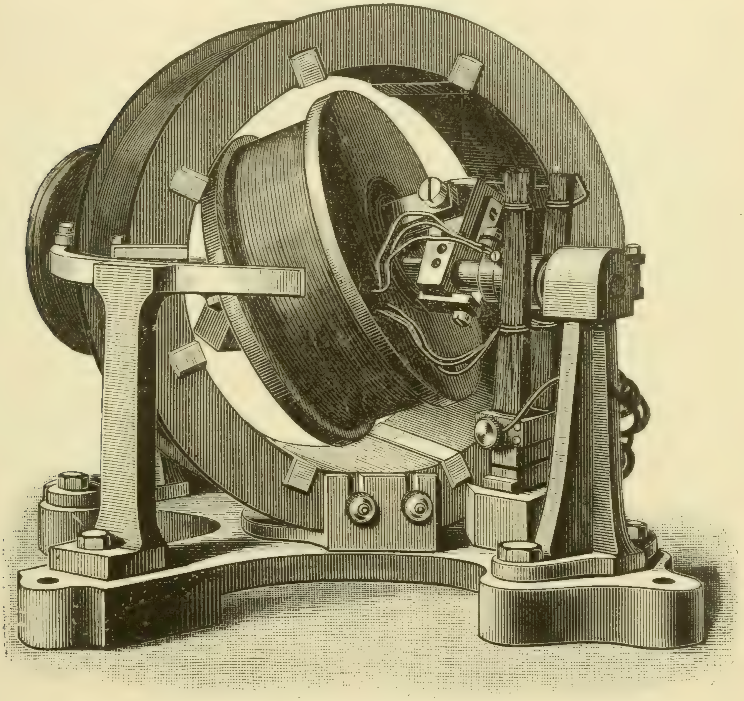


Fig. 394.

axis, O, and revolves between the poles of two electro-magnets, N S. The obliquity of the bobbin is such that, in each revolution, it presents the edges of A and B alternately to the poles of N and S, and alternating electric currents are set up in the coil of A. Fig. 396 shows a construction in which the bobbin B, fixed obliquely on the axis O, revolves within an oblique bobbin, C, which has an iron sheath, F, presenting interior polar edges toward the edges of B. The electric currents generated in the coil of B are collected and converted into currents of the same direction by means of a commutator, D. In the construction shown in fig. 397, the exterior bobbin is of soft iron. The commutator D may be applied to alternate the currents in the coil C, those in the coil B being in the same direction, collected

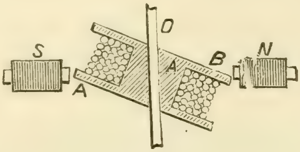


Fig. 395.

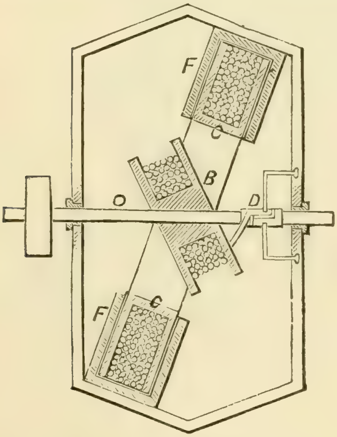


Fig. 396.

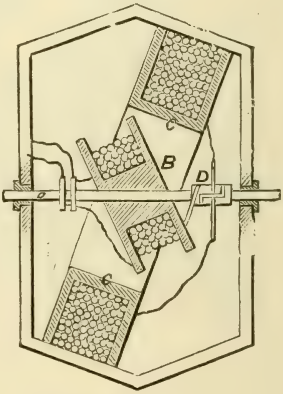


Fig. 397.

in the usual way by rubbers bearing on rings, E. In this case the internal bobbin B need not be of soft iron. When the machine is of large diameter, the interior bobbin A may be, as shown in fig. 398, merely a ring of iron fixed on a wheel of non-magnetic material.

The advantages attached to these machines are several, and, among the more important, simplicity of construction takes the first place. The coiling of the wire is perhaps more easily performed than in any other machine, as it is all winding of the most direct character; and the absence also of any nice adjustment constitutes a very important feature. M. Jablochkoff claims as his invention a dynamo-electric or electro-dynamic

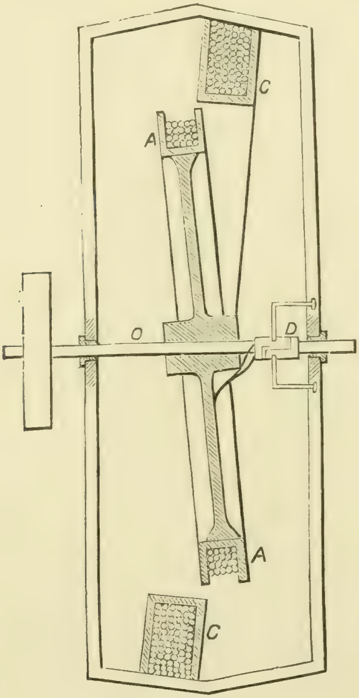


Fig. 398.

machine, wherein a magnetic coiled bobbin revolves between or within polar fields, the bobbin being fixed obliquely on its axis, so as to present its opposite edges to opposite fields alternately in each revolution.

GULCHER'S CONTINUOUS CURRENT MACHINE.

Fig. 399 represents the Gulcher machine, in which the magnetic field is produced by eight electro-magnets of oval form, arranged in two sets of force, with their free ends directed toward one another, and at their opposite ends attached to two vertical circular frames, carrying at their centres the bearings in which the main shaft of the machine runs; the opposite ends of each pair of magnets are connected together by a U-shaped pole piece, the open jaw of which is directed toward the centre of the armature ring. Between the two sets of magnets and within the pole pieces, is rotated a flat ring armature, the coils of which are wound after the Pacinotti type. Pacinotti's early machine had the coils wound between projecting teeth upon an iron ring. Gramme rejected these cogs, preferring that the coils should be wound round the entire surface of the endless core. To prevent wasteful currents in the cores, Gramme employed for that portion a coil of varnished iron wire of many turns. In Gulcher's machine, the ring core is made up of thin flat rings cut out of sheet iron, furnished with projecting cogs and laid upon one another. The parts of the coils which pass through the interior of the ring are comparatively idle. They cut very few lines of force as they rotate, and therefore offer a wasteful resistance.

Inventors have essayed to reduce this source of loss by either fitting projecting flanges to the pole pieces or by using internal magnets, or else by flattening the ring into a disk form, so as to reduce the interior parts of the ring coils into an insignificant amount. This is done in the Gulcher machine. The commutator is of the Gramme type, being cylindrical and divided into as many sections as there are coils on the armature. It is, however, of extraordinary length; consequently requiring collecting

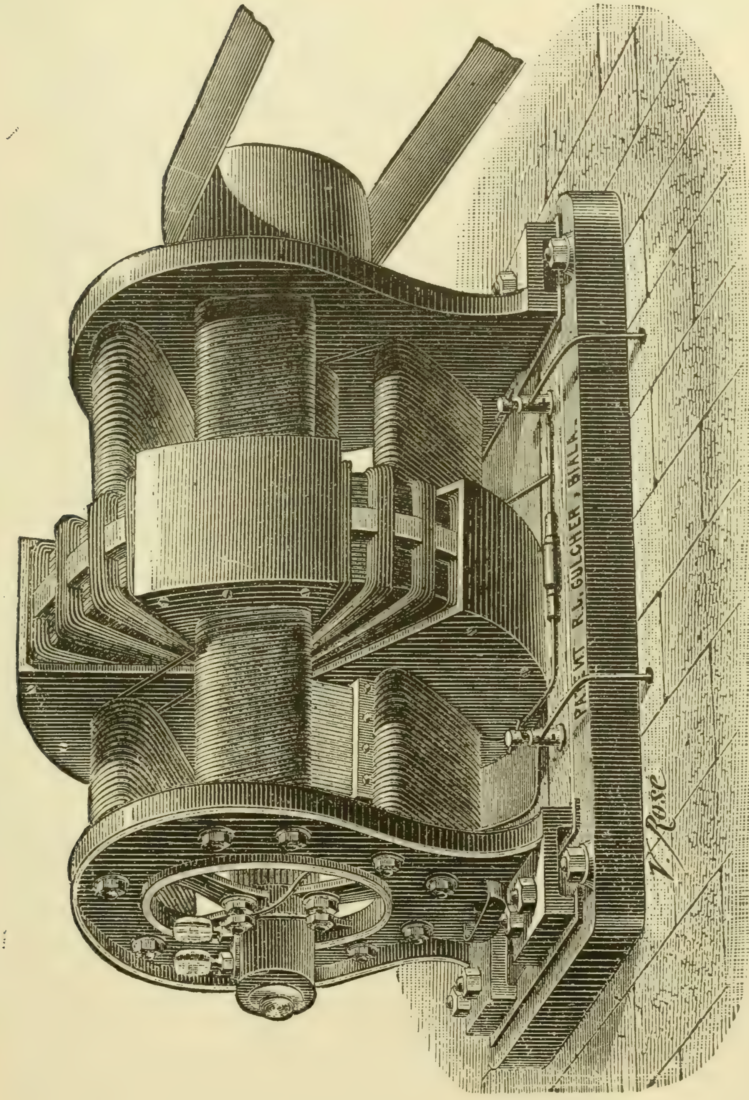


Fig. 399.

brushes of great width, and by this construction more perfect electrical contact is insured, and the sparking reduced. The magnet coils are wound with a double strand of copper wire, consisting of two thick wires twisted together; this arrangement being adopted for convenience in winding.

FERRANTI'S ALTERNATING CURRENT MACHINE.

Fig. 400 gives a general view of the Ferranti machine, which is identical in many respects with the Von Hefner-Alteneck alternate current machine. As in the latter machine, the electro-magnets form two crowns, with opposing poles. The point of difference is the armature, which, like the Von Hefner-Alteneck, has no iron cores in its coils; but which, unlike the latter, is not made up of coils wound round cores, but consists of zigzags of strip copper, folded upon one another.

There are eight loops in the zigzag (fig. 401), which depicts half only of the arrangement, and on each side are sixteen magnet poles, so that the moving parts are twice the angular breadth of the fixed parts. The advantage of the armature of zigzag copper lies in its simplicity of construction. Sir William Thomson, who is credited with being the real inventor of this armature, proposed originally that the copper strips should be wound between projecting teeth on a wooden wheel. He also proposed to use as field magnets a form of electro-magnet of the kind known as Roberts', and also used by Joule, in which the wires that bring the exciting current are passed up and down, in zigzag form, between iron blocks projecting from an iron frame. The Ferranti machine is 30 inches high; its foundation plate is 22 by 24 inches, and its total weight 1,300 pounds. The field magnets are 6 inches long; each core is surrounded by four coils of wire of No. 10 B. W. G. gauge; and the coils are connected in series, the resistance being 2.5 ohms; the vertical diameter of the cores is about 2 inches; their largest horizontal diameter 3.2 inches. They are excited by a small Siemens machine, giving a current of 21.5 ampères. The resistance of the armature is 0.0266 ohm.

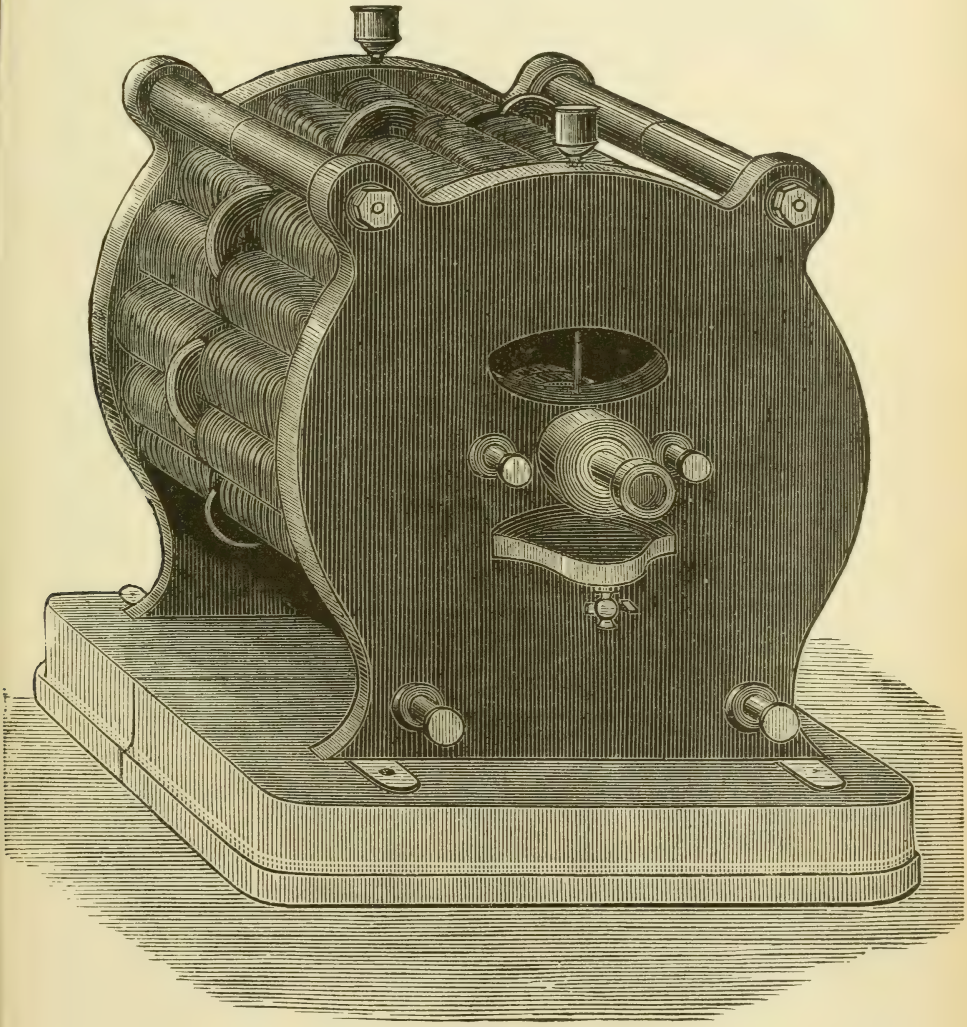


Fig. 400.

At some recent experiments in London, the Ferranti machine supplied the current for 300 Swan lamps of 20 candles each, three in series and each set of three in multiple arc. The expended force is stated to have been 26 horse-power, which would give twelve lamps of twenty carcels each for one horse-power.

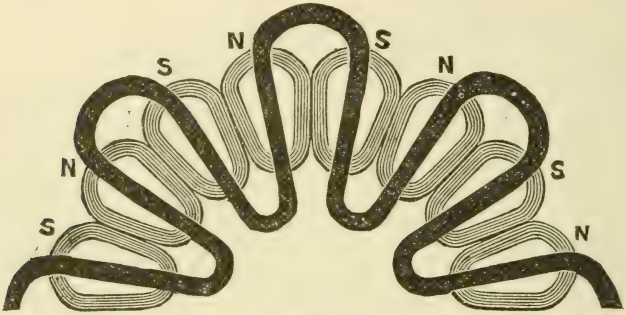


Fig. 401.

HOLCOMB'S ALTERNATING CURRENT MACHINE.

Fig. 402 gives a general view of the Holcomb machine, which was patented in 1880, and bears a strong resemblance to the machine recently brought out by Ferranti and Thomson. Indeed, the arrangement of the armature conductor, shown in figs. 403 and 404, seems to be substantially the same as that adopted by the latter gentleman.

It is stated in the specification that fig. 404 shows another way of arranging the conductor *d*, which consists of a disk, K, provided with the continuous grooves K′ K′, one on each side of it, the principal lines of the grooves being radial. The conductor is placed in the groove by laying it all around against one side of it, and so following around the groove until the different layers completely fill it, as shown at fig. 404, which is a transverse section of fig. 403. The wires in the two grooves are then connected together, and the ends d^4 and d^5 connected to the insulated collars. By this method of winding the conductor, the greater part of it is caused to cut the lines of magnetic force at right angles. Consequently, for a given useful

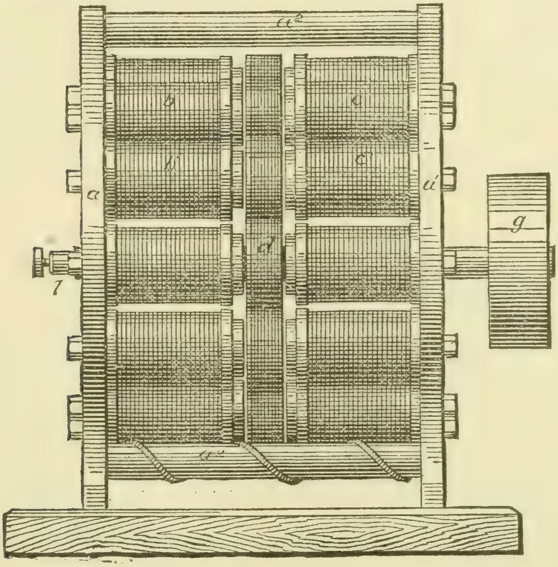


Fig. 402.

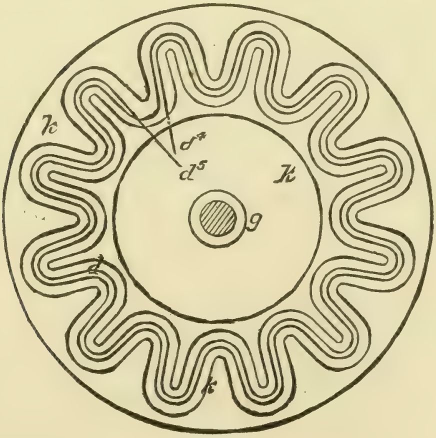


Fig. 403.

effect, less wire is required and the resistance is to such extent reduced. In another part of the specification it is stated, that the disk which forms the carrier for the armature conductor is made of a suitable diamagnetic material. Probably Messrs. Ferranti & Thomson have somewhat improved this form of armature in the details of mechanical construction ; and the use of a flat copper ribbon instead of insulated wire doubtless presents some advantages, although we are inclined to think, from the published reports of experiments made with the Gordon machine, that this may also involve serious disadvantages, unless the copper ribbon is made quite narrow.

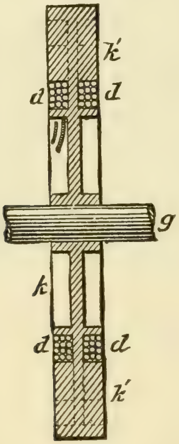


Fig. 404.

GERARD'S ALTERNATING CURRENT MACHINE.

The machine represented in fig. 405 consists of a movable inductor, whose alternate poles pass in front of an armature composed of a double number of oblong and flat bobbins, that are affixed to a circle firmly connected with the frame. There is a similar circle on each side of the inductor. The armature is stationary, and the wires that start from the bobbins are connected with terminals upon a wooden support that surmounts the machine.

This arrangement allows of every possible grouping of the currents, according to requirements; thus, the armature may be divided into two currents, so as to allow of carbons one inch in diameter being burned, or else so as to have four, eight, twelve, twenty-four, or even forty-eight distinct circuits capable of being used all together or in part.

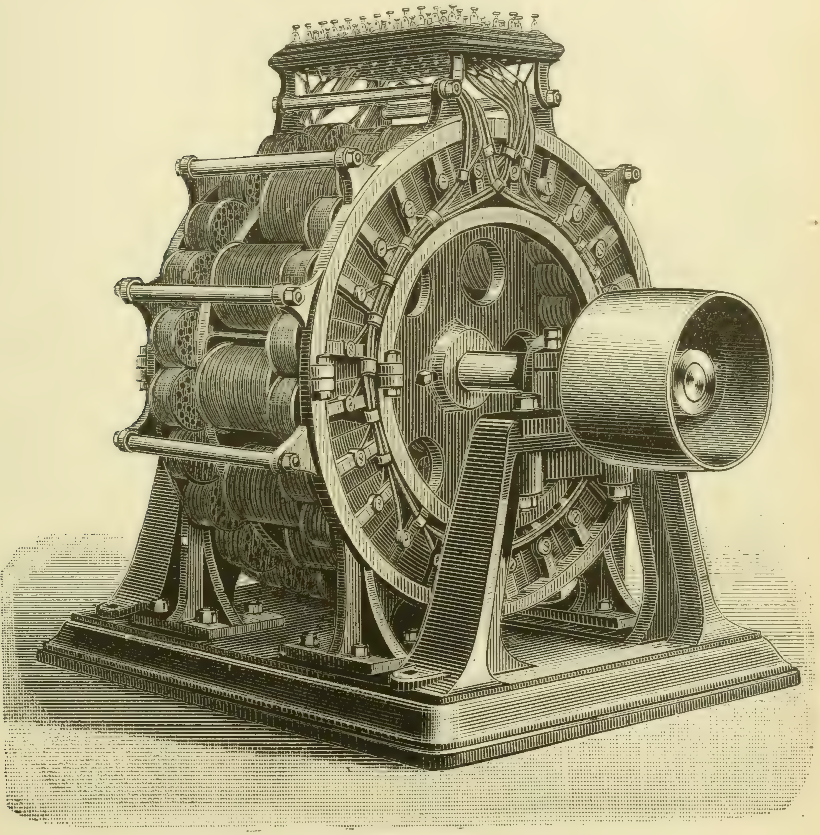


Fig. 405.

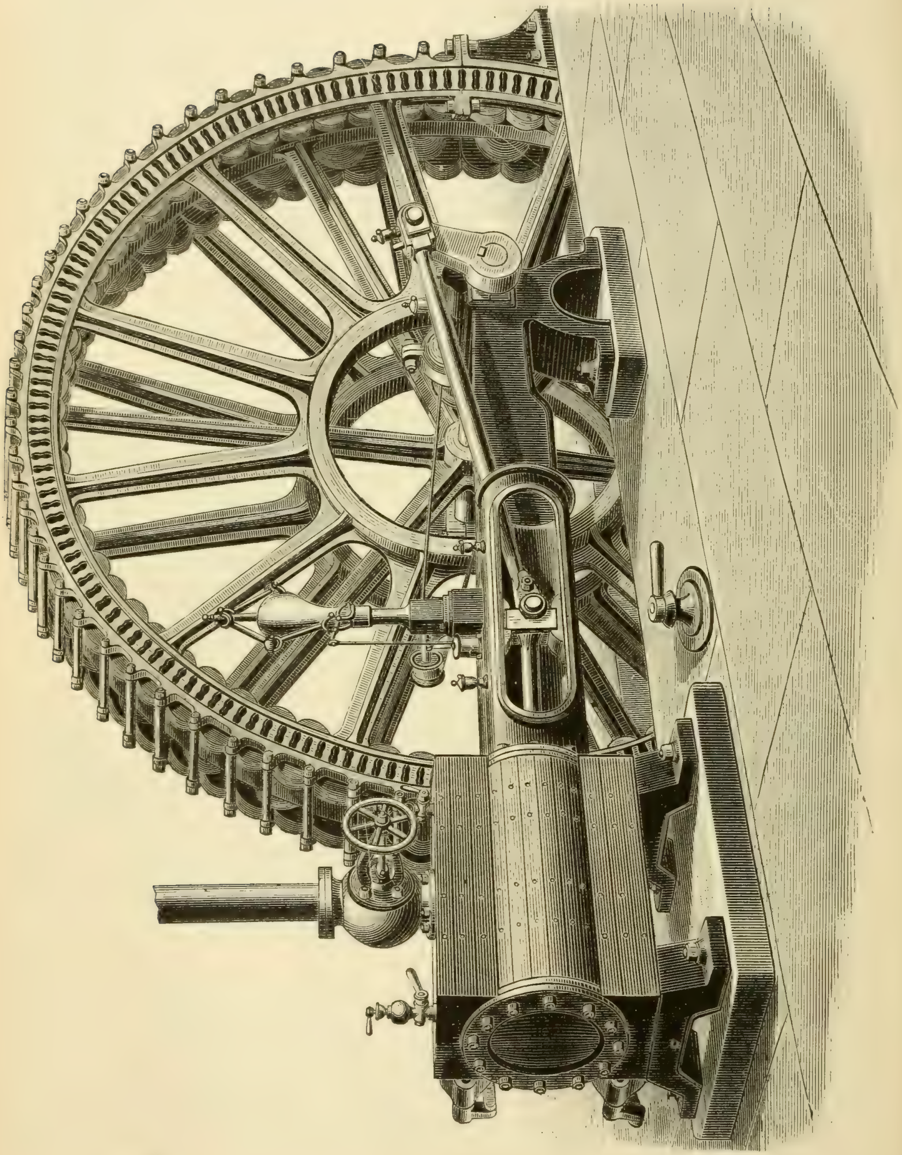


Fig. 406.

This machine has been studied with a view of rendering the lamps independent; and there may be produced with it, for example, a voltaic arc of an intensity of from 250 to 600 carcels for the lighting of a courtyard, or it may be used for producing arcs of less intensity for shops, or for supplying incandescent lamps. As each of the circuits is independent, it becomes easy to light or extinguish any one of the lamps at will. Since the conductors are formed of ordinary simple wires, the cost attending the installation of 12 or 24 lamps amounts to just about the same as it would in the case of a single cable.

Fig. 406 represents a Corliss steam engine, connected directly with a Gerard 250 horse-power direct connection alternating current machine. According to the inventor, this machine is capable of supplying 1,000 lamps of a special kind, called slide lamps, and a larger number of incandescent ones.

SIEMENS' EXTERNAL ARMATURE MACHINE.

In this apparatus Mr. Siemens has made the induced ring stationary and caused the inductor to revolve—the inductor in this case being an electro magnet having the form of a double T iron armature, the latter being formed of groups of wire wound around an iron cylinder. The wires of the different groups end in the radial pieces of a hollow collector, and internal brushes put them in connection with the internal movable electro-magnet.

Fig. 407 is a general view of the machine. The field magnet is shown partly in fig. 408. On the shaft carrying the field magnet there are two collars insulated from each other, one being connected with each end of the wire wound around the field magnet. The current which passes through the field circuit is consequently never reversed, and the polarity of each pole of the field magnet remains constantly the same. As this field magnet revolves it acts upon the ring in the same manner as if the ring itself rotated and the field magnet were stationary. Consequently, each section of the ring passes through a phase of induction lasting through half a revolution, during which the

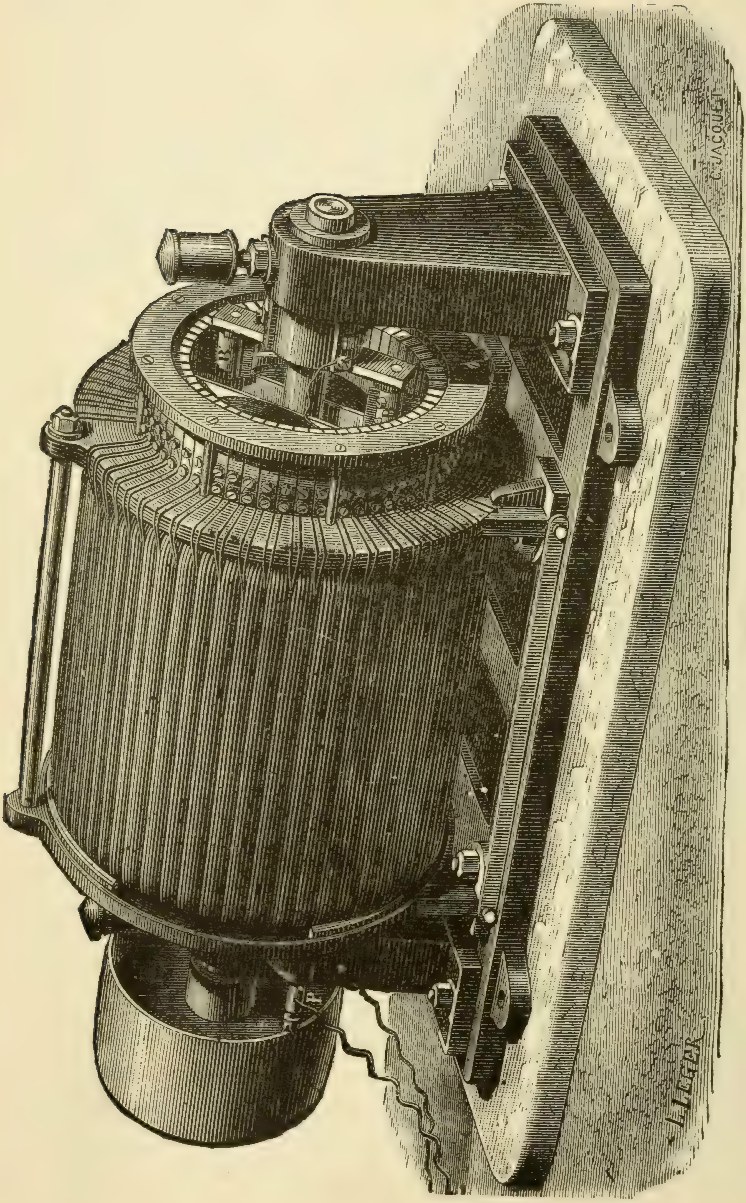


Fig. 407.

current is in a given direction, and then through another phase, during which the current is in the other direction. Each section is cutting lines of force of one polarity during one-half of the revolution, and of the opposite polarity during the other half. The sections of the armature are connected to a commutator in the same manner as in the Gramme machines; but as the commutator cannot revolve, the brush holders themselves revolve.

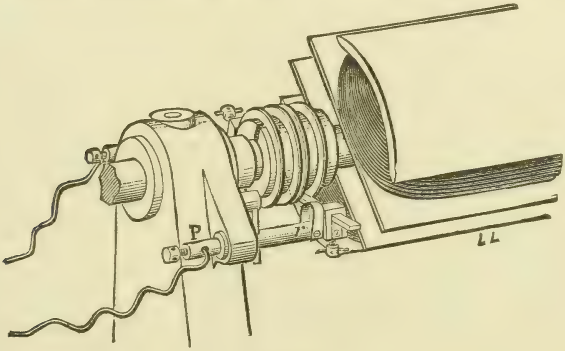


Fig. 408.

They are attached to the shaft of the field magnet, as shown at B, in fig. 407, and the brushes point outward on the inside surface of the commutator segment. The brushes are adjusted to make contact with the commutator at points corresponding to the neutral portions of the ring. The neutral portions of the armature are constantly running around in the direction of rotation, following the magnetic poles and keeping behind by merely a quarter of a revolution.

THOMSON'S SPHERICAL MACHINE.

Fig. 409 gives a general idea of the Thomson generator, and the disposition of its parts. The revolving armature is a hollow shell of soft iron secured to the central portion of the shaft between the bearings, and is wound externally with a copper conducting wire, constituting three coils permanently joined, surrounding the armature. This wire is fully exposed to the magnetic influence of the field poles, which inclose the armature almost completely. The field magnets, which surround the armature, are cast iron shells, wound outside with many convolutions of insulated copper wire, and are joined externally by iron bars to convey the magnetism. These outer bars serve also as a protection to the wire and armature of the machine. The coils of wire upon the field magnets surround not only the iron poles, but likewise the revolving armature. The shaft, which is mounted in babbitted bearings of ample size, is of steel, finely turned and perfectly true. The armature wire is kept cool by an active circulation of air over its whole surface during revolution. The commutator, which is mounted upon the end of the

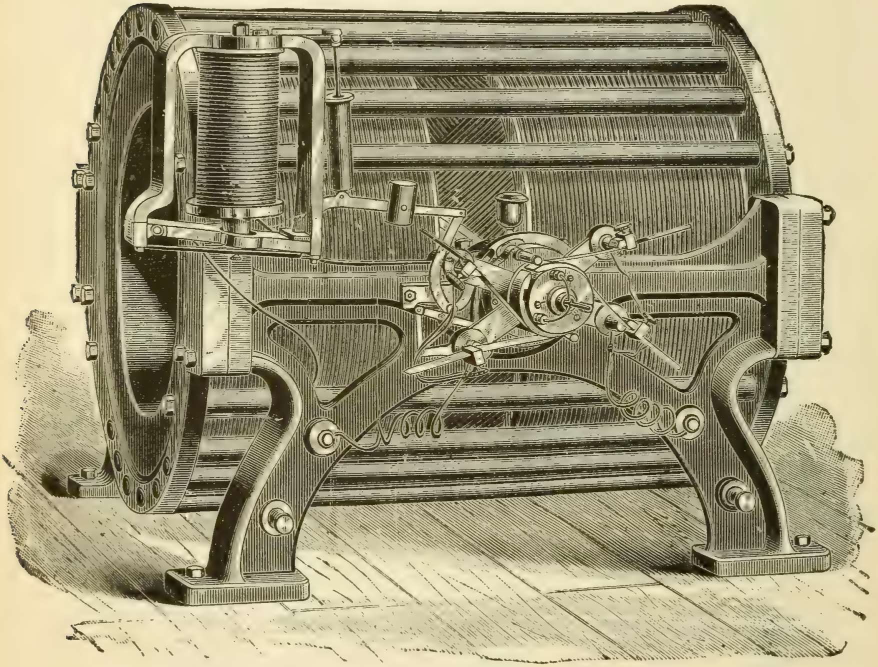


Fig. 409.

shaft, and has attached to it the three wires, coming from the armature through the tubular shaft, consists of three segments of a copper ring, made so as to be removable in a moment for cleaning or replacement, and are mounted upon a metal support, and surrounded on all sides by a free air space. Besides this, the commutator is sustained by support carried in flanges upon the shaft, which are coated with hard rubber. The three commutator segments constitute a single copper ring, cut into equal pieces by slots across its face. Four slit copper springs, or collectors, bear lightly upon the commutator, and serve to take up the current and convey it to the circuit. These commutator brushes are carried by movable supports, and their position is automatically regulated, so as to control the strength of the developed current.

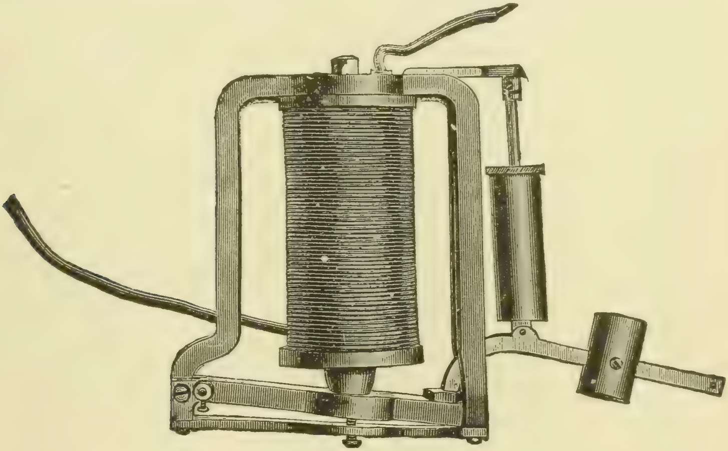


Fig. 410.

Fig. 410 shows the automatic current regulator, which consists of an electro-magnet attached to the frame of the generator, the movable armature of which has connections with the supports of the commutator brushes for controlling their position. The regulator magnet is so formed as to produce a uniform attraction upon its armature in different positions. This is accomplished by making the pole of the magnet paraboloidal in form, with an opening in the movable armature to encircle it. The armature is hung on pivots, so as to be free to move to and from the regulating magnet on changes in the current traversing the latter, and being connected to the commutator brushes, automatically adjusts their position. By this means the power of the generator is adapted to run any number of lights within its limit of capacity. The manner of its action is to control the generation of the current at its source in the armature, and it does this by combining certain electrical actions so as to obtain a differential effect, so that the strength of the current furnished shall always be proportional to the amount required.

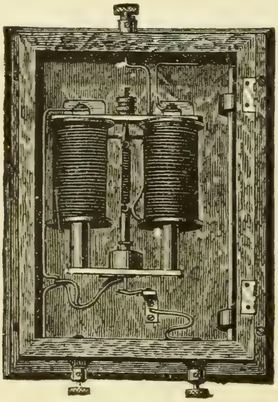


Fig. 411.

On the larger generators there is combined with the regulator magnet an exceedingly sensitive controller magnet, fig. 411, governing the regulation, and by the accuracy of which the smallest variations of current are counteracted. The controller magnet is contained in a box placed near the generator, and consists of a delicate double axial magnet controlling the admission of the current to the regulator upon the generator. So perfect is the action, that in a circuit of thirty lights, one-third of them may be removed in rapid succession without appreciably affecting those that remain.

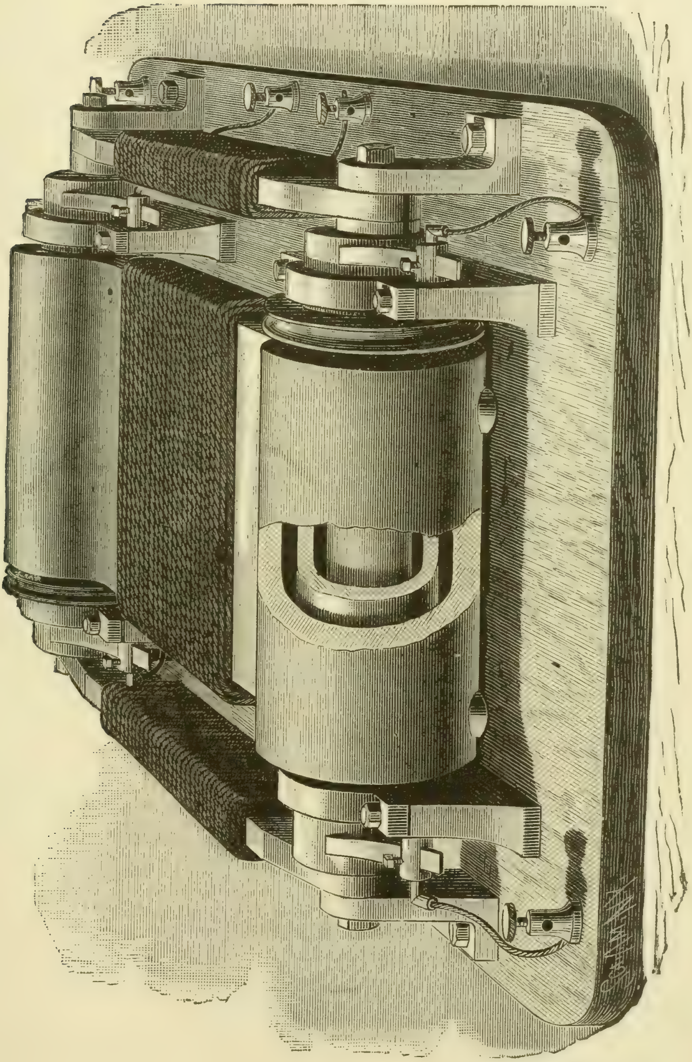


Fig. 412.

DELAFIELD'S UNIPOLAR CONTINUOUS CURRENT MACHINE.

Fig. 412 is a general view of the Delafield machine, whose armature has neither wire, bars nor commutator. The machine consists of a field magnet having hollow cylindrical polar extremities, in each of which a tubular armature revolves, the bearing of the armature being at the ends of the cylindrical poles of the field magnet. An auxiliary field magnet, composed of the side bars and cylindrical pole extensions, extending through the armature axially, completes the arrangement, and acting together with the outer magnet produces a strong magnetic field surrounding the armature on all sides. The current is conducted from the ends of the armature by wires connecting with the armature journals, and with springs bearing on the ends of the armature. The springs are applied to insure a constant connection.

In operating the machine the current from one armature may be used to excite the field magnets, or the current from both armatures may be taken through the wire of the field magnets, or the field magnets may be excited by a small high tension dynamo-electric machine, and the entire current of the armatures may be applied to outside work.

ZIPERNOWSKY'S MACHINE.

The Zipernowsky generator consists of a cylindrical armature, wound lengthwise with coils of insulated wire, which revolves within an electro-magnet; the latter consisting of an iron ring also wound over sections of its circumference with coils of insulated wire, so as to produce a number of successive polar fields of alternating polarity. The spaces on the ring between the coils are formed with inwardly extended pole pieces, which embrace the greater part of the circumference of the armature. The coils of the armature are wound in the form of rectangles, with their long sides parallel to the axis, the width of each coil being such that its two sides are at the same time approaching and leaving two of the polar fields. The core of the armature, for very strong currents, is made of wrought-iron plates, whose continu-

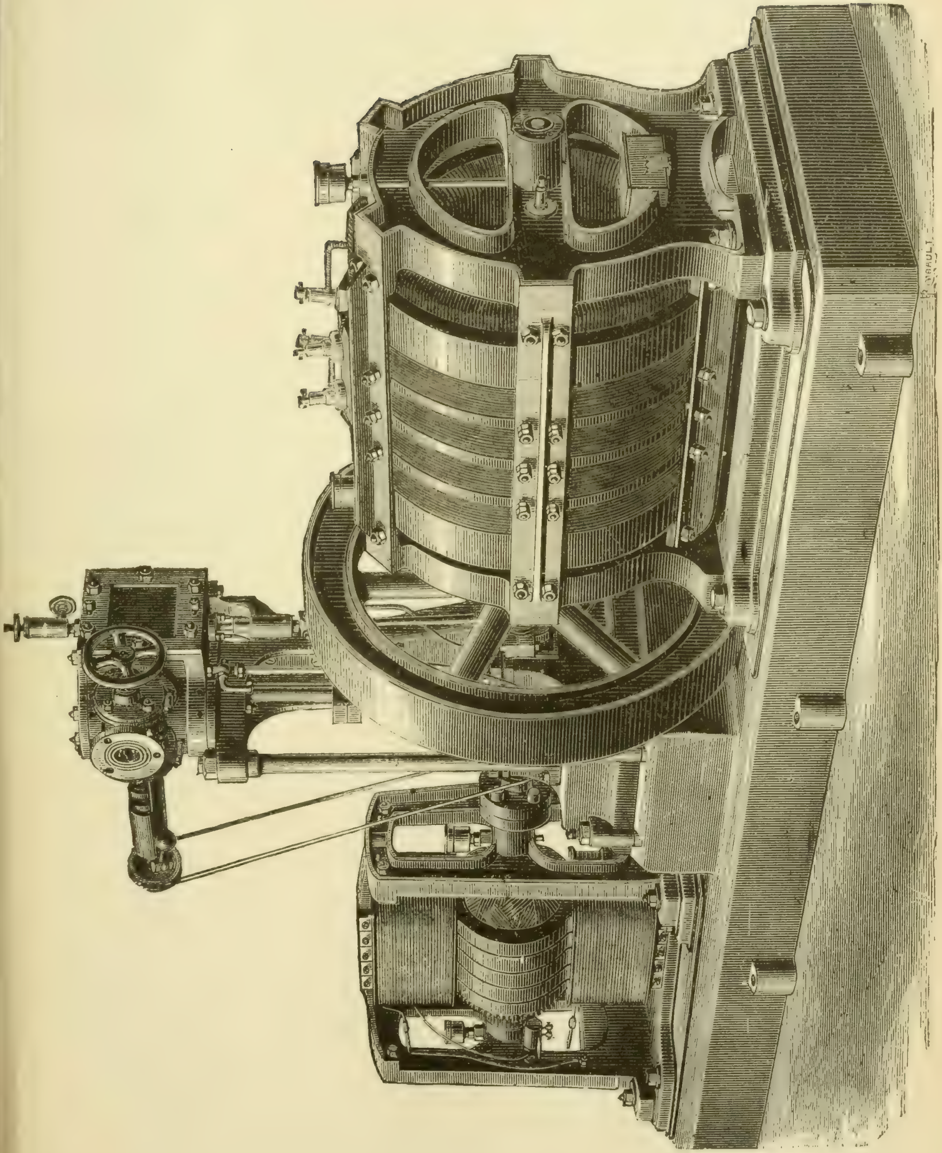


Fig. 413.

ity is broken; and for producing continuous uniform currents it is formed of spiral-shaped rings of insulated iron, wound round a cylinder of non-magnetic material. The currents are collected by a cylindrical commutator, which, in order to diminish the wear and tear of the plates, is lubricated by pure petroleum, drawn from a tank placed above it, through a porous wick, which extends from the tank in such a manner as to bear tangentially against the commutator. The armature is made hollow and has openings in its ends and periphery, so that the air, which is put in motion by internal oblique fans, may keep the machine cool.

The Zipernowsky generator, although constructed as a self-exciting machine, is generally fitted with a separate exciter. In case it is to be used as a self-exciting machine, the generator is fitted with a switch, by means of which the difference of potential at the terminals of the machine can be made to remain constant and independent of the number of lamps in the circuit; when, however, a separate exciting machine is used, a rheostat is employed to effect the same result.

Fig. 413 represents a vertical Gwynne engine coupled direct on one side of the Zipernowsky generator, and on the other side to the exciting machine. The Zipernowsky generator has been successfully used for supplying currents for electric lights for various kinds of farming work during the night. The advantages of working thrashing machines at night, particularly during harvest time, are well known. It is stated, as the result of three years' experience, that twelve thrashing plants fitted with the electric light will produce more work than sixteen without it. The mode of driving the generator direct from the portable engine, and without the use of an additional loose pulley, is shown in fig. 414, where the large circle A represents the driving pulley or fly wheel of the portable engine, B that of the generator, and C on the right that of the thrashing machine. The two driving belts work one over the other on the engine fly wheel, and the generator is fixed on a special frame at a convenient distance between the engine and the thrashing machine.

The Zipernowsky generator has also been successfully used in supplying currents for lighting the National Theatre in Buda-Pesth. Fig. 415 represents a small block plan of this theatre where A is the stage, B the auditorium, C the engine and machine house, and D the chimney. The engine house is in a building adjoining the theatre, where a spacious basement was

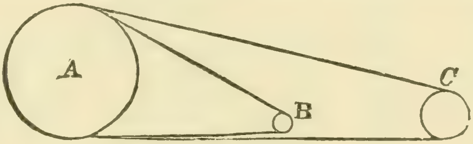


Fig. 414.

available; this basement (figs. 416, 417 and 418) is divided by a wall into two parts, the smaller of which contains two water tube boilers, *d d*, of Buttner's type, one only being required for regular work, the second forming a standby. The steam supplies two vertical compound Gwynne engines, which are placed one at each end of the engine room, the main shafting being

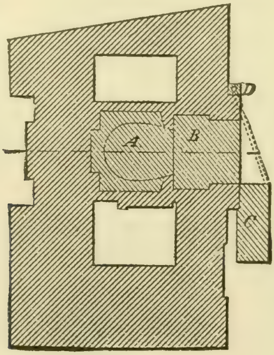


Fig. 415.

arranged between them, with a friction coupling at each extremity, by means of which either one or the other, or both, engines may be used to drive the shafting. To the latter are keyed five carefully balanced driving pulleys, *i i*, running at 180 revolutions per minute, and these carry the belts for five alternating current machines, specially designed for lighting theatres with

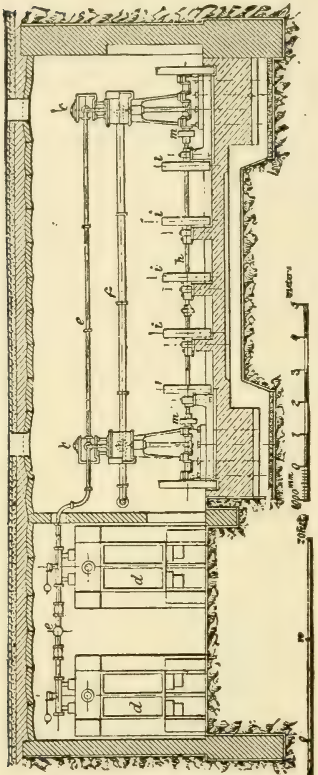


Fig. 417.

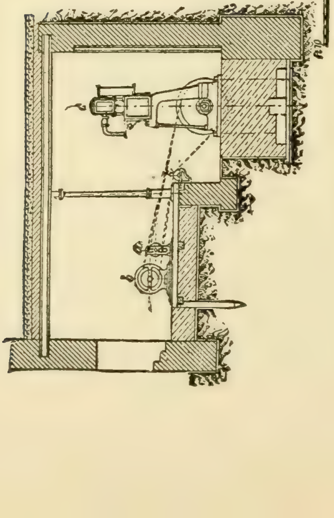


Fig. 416.

incandescent lamps. Each machine is capable of supplying current for 250 twenty-candle power incandescent lamps, requiring a difference of potential of fifty-six volts and a current of 1.4 ampères each. Four machines are kept at work, the fifth serving as a reserve, and being for this reason electrically connected in such a manner that it can replace any one of the others. Each generator, *b*, is fixed with its exciting machine, *a*, on a framework, by means of which the continuous driving belts

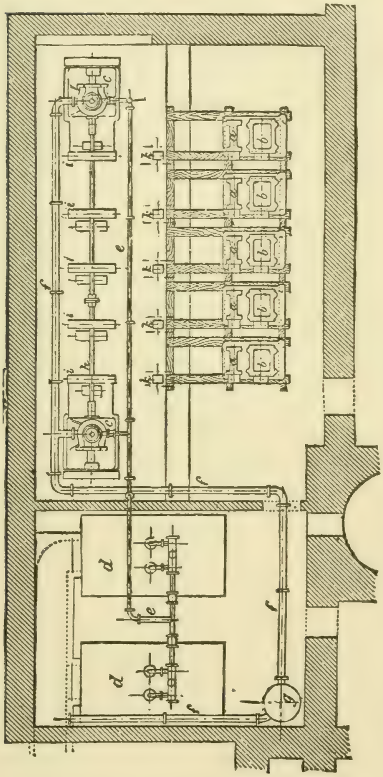


Fig. 418.

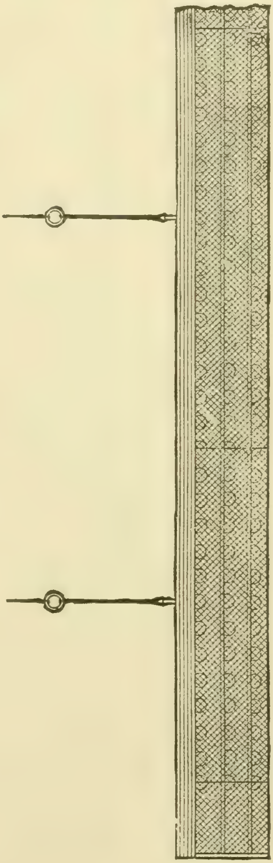


Fig. 419.

can be stretched while at work, an arrangement which was considered expedient for the safety of the installation.

The generators have each twelve induction coils; twelve circuits are taken off of these, and are arranged parallel to supply the different lamps. The wires are led to a switchboard fixed on the stage, from whence a larger or smaller number of coils can be thrown into circuit, and the volume of light thereby varied. The arrangement in the auditorium, where 128 lamps are fixed, admits of nine different grades of light, while for the stage, where the lights are divided, there are seven flies with sixty lamps each (figs. 419 and 420), the power of which can be varied in twenty-one different grades. In addition, each fly, as a whole, can be varied in three degrees of light power, and each one of the flies is fitted, as shown in figs. 419 and 420, with three rows of colored lamps, sixty in each row, so as to enable the effects of morning or evening or bright daylight to be produced easily.

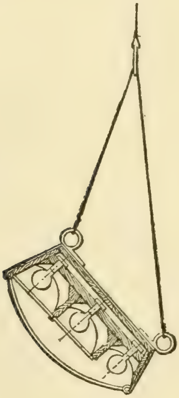


Fig. 420.

Fig. 421.

The generators used in this installation are alternate current machines; an extended experience having proved that the lamps last much longer when supplied by alternate current machines than when supplied by continuous current machines. Experiments showed that with a continuous current the carbon filament of incandescent lamps showed signs of wear at the point where the positive current enters after about 500 hours, producing a black spot on the globe (fig. 421). On the other hand, when working with alternate current machines, the lamps burn without deterioration for 1,200 hours and upward, after which time they begin to show signs of wear throughout the carbon, a slight deposit is formed on the globes, the carbon becomes thinner, the resistance greater, and the light less intense.

These experiences have been partly gained at an installation consisting of 220 incandescent lamps at the steam mills at Buda-Pesth, and also at another smaller installation of sixty-four lamps at the flour mills in Erlau. At the first named place, after ninety-five days' working, the 220 lamps had been burning for 980 hours each, in which time fifteen had failed, while six more had been accidentally broken. At the latter establishment the lamps have burned for over 1,400 hours, during which time, according to the manager's statement, not one lamp had been destroyed. These results are very strong evidence in favor of alternate current machines for incandescent lighting, since the cost for light is reduced almost to that of coal and lubricants.

The Zipernowsky machine is equally suitable for arc lamps. At the late electric exhibition of Trieste, the Csarda was lighted with eight arc lamps so successfully that the Exhibition Commission gave an order for lighting the whole of the grounds with thirty-two arc lamps of 600-candle power each. The generators supplying this installation were placed at Lloyd's Arsenal, a distance of over three miles from the exhibition grounds, which distance did not, however, interfere with the successful results of the installation.

The most brilliant effects in connection with this exhibition were, however, produced on board the Lloyd steamer Berenice, which, on the occasion of a visit by the crowned heads of Austria, was most magnificently illuminated with sixty-two incandescent and four arc lamps. The ship's deck was transformed into a ball saloon, beautifully decorated and artistically and most successfully lighted.

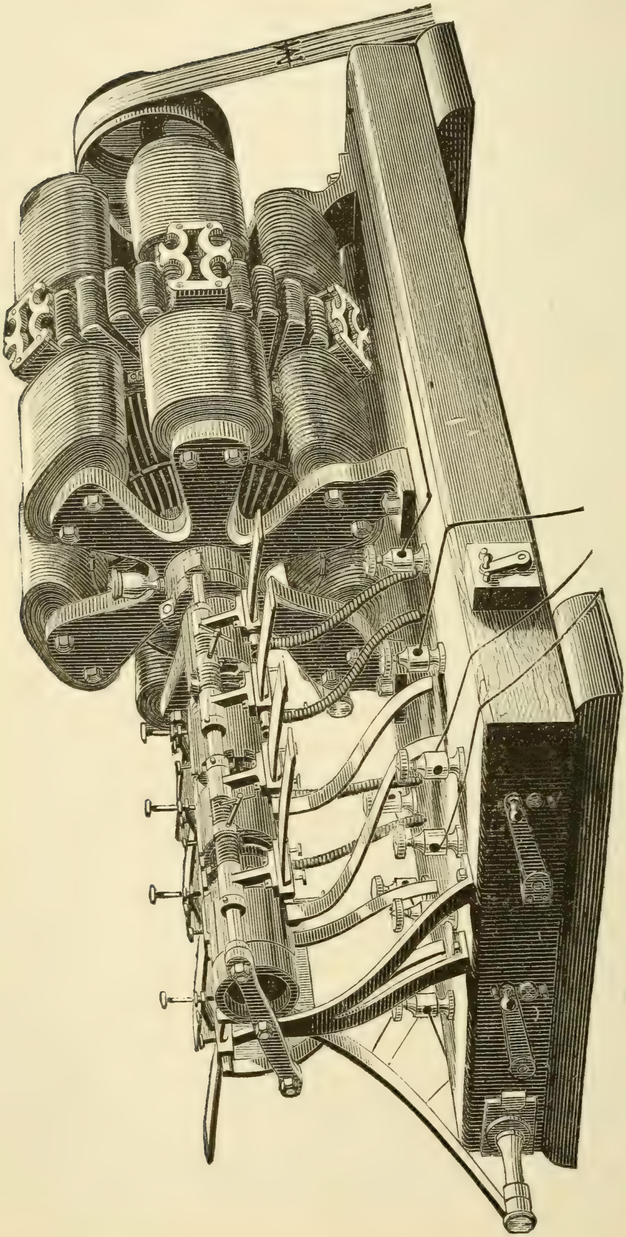


Fig. 422.

So successful were these experiments, that at present several installations are making for Lloyd's steamers. Several other successful installations may be mentioned, one on board the troopship Custazza, with 130 incandescent lamps, which has given great satisfaction in Austrian marine circles, and one for street illumination in Szegedin. The main street, nearly a mile long, leading to the railway station, is lighted by 20 candle incandescent lamps, while the place in front of the station is lighted by four arc lamps. This is the first installation for street lighting in Austria in which the two systems of lighting have been adopted side by side, and the result is said to be highly satisfactory.

MULLER'S MULTIPLE CIRCUIT MACHINE.

Müller's machine, which is shown in perspective in fig. 422 and in transverse section in fig 423, furnishes four separate circuits with electric currents for as many different uses. By duplicating some of the parts of the machine, the number of

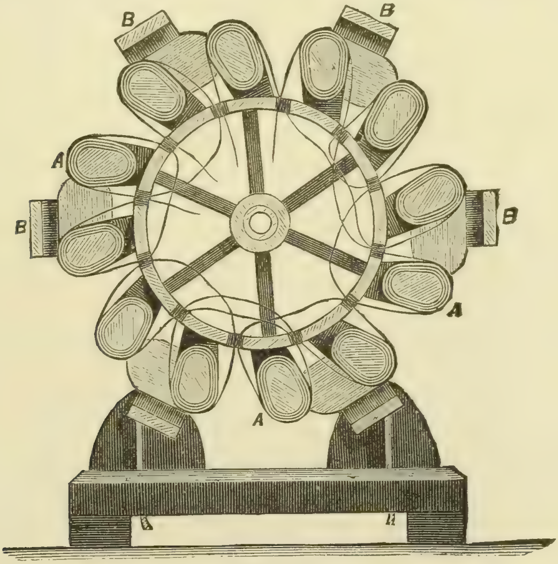


Fig. 423.

different circuits supplied may be still further extended, and the currents used interchangeably for arc and incandescent lights, electric motors, storage of electricity, and for many other purposes to which electricity is applied. The production of a number of separate and distinct currents in one machine is a feature claimed by Mr. Müller as one of great utility.

This result is secured by employing a series of armature coils, A (fig. 423), in an armature wheel rotating between the poles of two powerful multi-polar field magnets, B, the several bobbins being divided into series, each of which is connected with a series of commutator bars forming commutator cylinders, each being provided with a pair of collecting brushes, which deliver the current to the circuit upon which it is used. To economize power, the armature coils are arranged diagonal to the poles of the field magnet, which allows the armature coils to be removed from the vicinity of the poles of the field magnets with less force than would be required were the bobbins exactly radial; and the form of the armature wheel creates a current of air throughout the machine which keeps all of the parts cool. The machine in ordinary working makes about eight hundred revolutions a minute.

FERRARIS'S UNIPOLAR MACHINE.

The general appearance of the Ferraris generator is similar to Von Hefner-Alteneck's, shown in fig. 367. It has two horseshoe magnets, connected by their ends of like polarity. Between them are two cylindrical spaces destined to receive the revolving armatures. There are thus two magnetic fields of different polarities, the one above and the other below the polar expansions of the magnets, the lines of force of which are collected by the two axles of the armatures, these axles being connected together by two friction pulleys, and thus form a horseshoe armature, magnetized by the electro-magnets. The axles and pulleys are of soft iron. Around the axles, and insulated from them, there are two cylindrical armatures, composed of bars of copper. The armatures are insulated from the revolving axles, and are connected in tension in order to double the electromotive force of the current.

To diminish, as far as possible, the friction of the collars without having recourse to oil, which would hinder the passage of the current, the interior surface is fitted with lubricating rods composed of an alloy of thallium.

The bars intersect normally the lines of force, which are strengthened as much as possible by filling the space between the axle and the copper armature with small disks of iron. The small space between the disks and the bars produces a ventilation sufficient to cool the armature.

The circuit of each branch of the electro-magnets is connected with a commutator, as well as with the conductors of the shunt intended for excitement. The magnets may be grouped at will in tension or in quantity, or in two tension groups connected with each other in quantity. There is also a means of changing the system of excitement either by derivation or by the current of an auxiliary machine, and of introducing into the exciting circuit resistances which serve to graduate the magnetic field and the electromotive force. By means of an intercalated commutator the potential of the current produced may be varied very widely. The machine may be applied, without any modification, to many operations which require currents of different tensions.

SCHWERD AND SCHARNWEBER'S CONSTANT CURRENT GENERATOR.

In this machine the poles of the magnetic field are reflected and prolonged inward so as to act on the inner portion of the armature. In the outward appearance of its magnetic field it recalls the Von Hefner-Alteneck machine, fig. 367.

The field magnets of the latter, however, are made of narrow pieces of wrought iron screwed side by side to the end pieces, and leaving slits between them for the purpose of localizing and obviating the induction of Foucault currents. In the Schwerd and Scharnweber machine the field cores are constructed of one piece of cast iron, and the prolongations of the poles, by which the inside of the ring also is made to cut lines of force, form an inward extension from the iron caps bolted to the poles. The inner surface of the armature revolves very closely to the outer surface of each prolongation, which forms a portion of a circle, and thus the wire inside the ring is acted upon by whatever magnetism there may be present there.

The armature, which is cylindrical in shape and wound in the same manner as the Gramme ring, is fastened to the axis at its centre. The polar prolongations extending inward from each side, leave a space at the centre, in which a metallic spider carried by the shaft can move. The armature is secured to the spokes of this spider, which expand at their outer extremity, and are fitted to the armature core at its centre, a space being left between the sections of wire for the purpose.

HOCHHAUSEN'S CONTINUOUS CURRENT MACHINE.

The Hochhausen generator, manufactured by the Excelsior Electric Company, is shown in perspective in fig. 424. The framework consists of two thick plates of iron, cast in one piece with the base and top, and expanded outward at the middle to make room for the armature. To provide a bearing for the pulley end of the armature shaft, the two curved portions of this frame are joined by an arm bolted to each curved plate. The bearing is at the centre of this arm, which serves to insure greater solidity in the framework. The bearing at the commutator end of the shaft consists of a strong A shaped standard, separately bolted to the platform. To remove the armature, in case repairs or changes are to be made, it is only necessary to unscrew this standard and remove the pulley from the shaft of the armature, which may then be pulled out whole. The field magnet cores are slipped inside the framework, and are held in place by large bolts passing through the top and the base respectively. The flat plates of the framework, lying close to the wire of the field magnet, act as the outer portion of a tubular magnet, or as the back piece or yoke which joins the two arms of an ordinary U magnet.

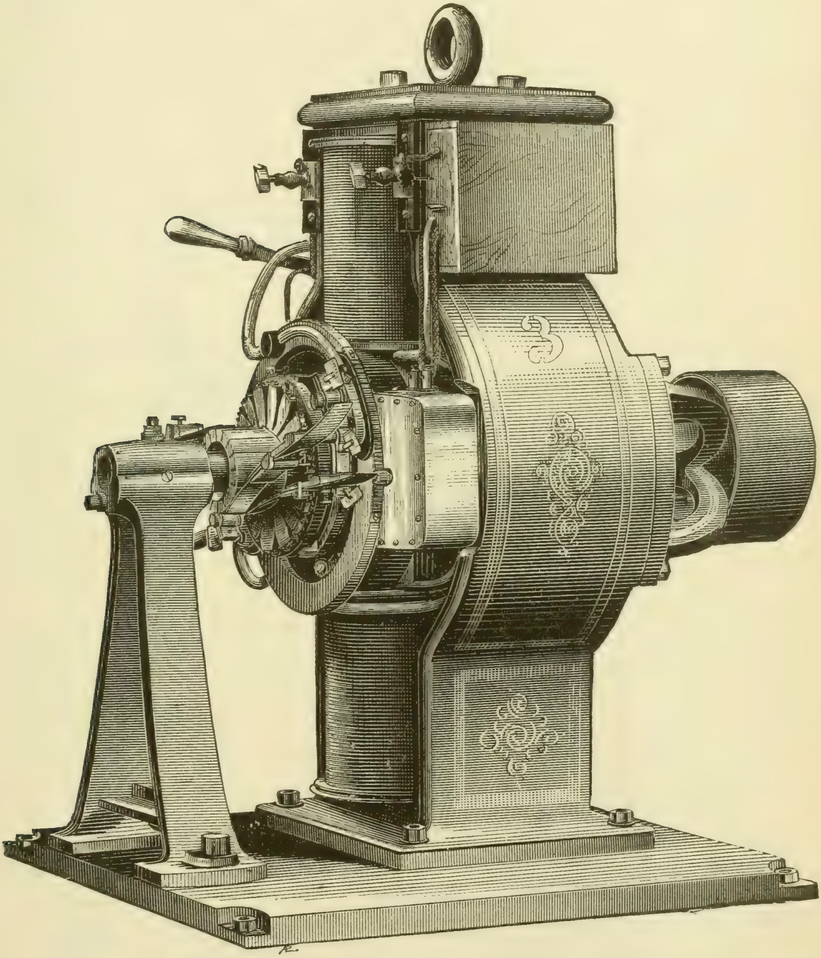


Fig. 424.

The armature is of the cylindrical form, with laminated core; the same as if made of a number of thin iron disks placed close together, each disk being made of four pieces. Two of these quarter disks are shown separately in fig. 425, which represents two of the four sections of an armature core united together, one being partially dissected. The quarter disks are punched out of thin sheet iron about one-sixteenth of an inch thick. The two denticulations at one end are farther apart than those at the other. This is because there are two rows of holes in the flat transverse pieces, into which they fit and by which they are held in place. In fitting them the narrow and wide dented ends are alternated. Otherwise it would be necessary to make all the holes in a row, thereby greatly weakening the flat piece. To give solidity to each section there are three quarter circle pieces of malleable iron, one in the middle and one at each end, all three held firmly between the two flat transverse pieces by screws. The pieces at either end are rounded, so that the wire may touch evenly. To prevent the quarter disks from touching each other, a hole is bored through every alternate one and a piece of wire is passed through and bent. The lower one

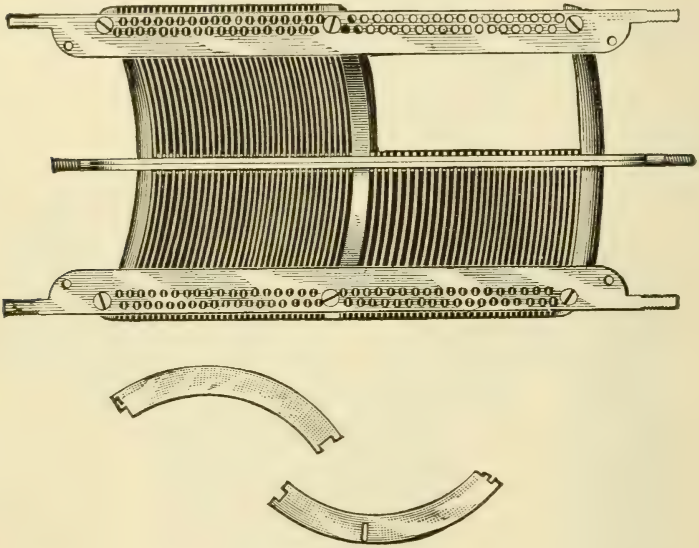


Fig. 425.

in the figure shows one of these wires. Sixteen sections are employed.

A marked advantage in this manner of constructing the armature is that the sections of wire intended for the armature can be wound separately in a mould bobbin. Not only is the winding more easily done, but the chances of its being faulty are much diminished, and the insulation can be more easily attended to. Fig. 426 shows one of these sections ready to be slipped on the armature core. The outside layers are protected by cotton, paper, or other material, and the bends are tightly wound with cotton cloth and painted, so that the section may retain the form given it in the mould. The ends of the wire are also looped and insulated. To place the sections on the core one of the transverse strips is unscrewed and they are slipped into place. Each core section receives four wire sections. Fig. 427 shows one-half of the armature core with its wire sections in place.

The core sections are connected to each other so as to form a ring by means of screws which join the contiguous flat transverse pieces together. The holes for these screws are shown near the ends of the flat pieces in fig. 425.

And after two sections are connected together, the ends of the two flat pieces are rounded and threaded, as shown in the figure. There are four of these screw tips at each end of the cylinder, and it is by means of them that the armature is mounted upon its shaft. For this purpose brass spiders are used. These tips pass through four holes in the circumference of the spider, but are insulated from the spider by bushings and washers of gelatinized fibre. Then, by means of nuts, the spiders are firmly secured to the armature. The circumference of the spider at the commutator end of the armature carries four square projections resembling the jaws of a lathe chuck, into which the commutator disk, fig. 28, is received. The commutator segments are insulated from each other and from the shaft only by air spaces. It is therefore easy, by slipping a piece of cardboard between the segments, to dislodge any copper dust, oil or dirt, and thus obviate those short circuits between segments which sometimes lead to the burning of an armature section.

Each segment has a tail piece disposed radially on the disk

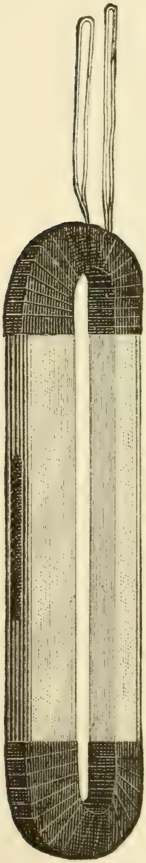


Fig. 426.

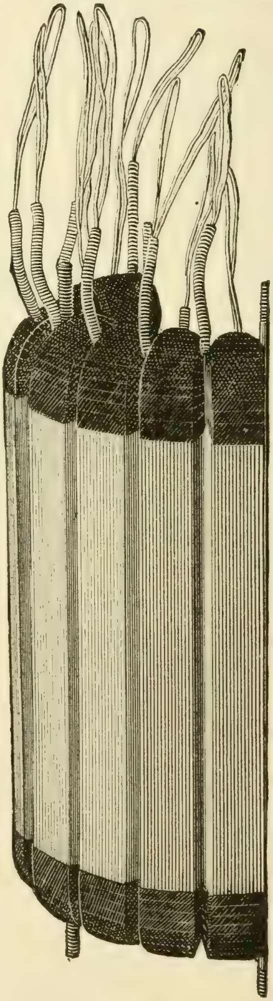


Fig. 427.

and screwed to it firmly. The disk, which is of slate or soapstone, has a small hole near the outer end of the radial portion of each segment, through which the wire leading from each connection between two contiguous sections of the armature is passed, for the purpose of making connections to the commutator. These connections are not soldered, but are made by inserting the end under a small brass clip, which, by means of two screws, holds it firmly against the radial portion of the commutator segment. For convenience, the commutator segments are numbered in rotation. These clips are shown on the radial ends of segments 7, 8, 9, 10, in fig. 428.

This armature presents many advantages which will suggest themselves to electricians. Its laminated structure, with free spaces between the wire sections, affords easy and effective ventilation, by which the armature is kept quite cool even when run for a long time. Another advantage is, that the sections are all so nearly alike that the armature is quite symmetrical when bound with fine wire, and consequently needs but little balancing, and can be revolved closely to the field magnet. The depth of wire on the outside of the core is about half an inch—rather more in the larger and rather less in the smaller ones.

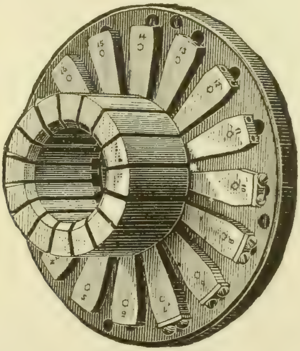


Fig. 428.

For a machine adapted for 25 arc lights, the depth of wire is $\frac{9}{16}$ inch. The No. 16 gauge wire in each section occupies 11 layers of 22 convolutions each. The diameter of the armature is $13\frac{1}{8}$ inches, only one-sixteenth inch play being allowed between it and the field, which has a diameter of $13\frac{1}{4}$ inches. The total

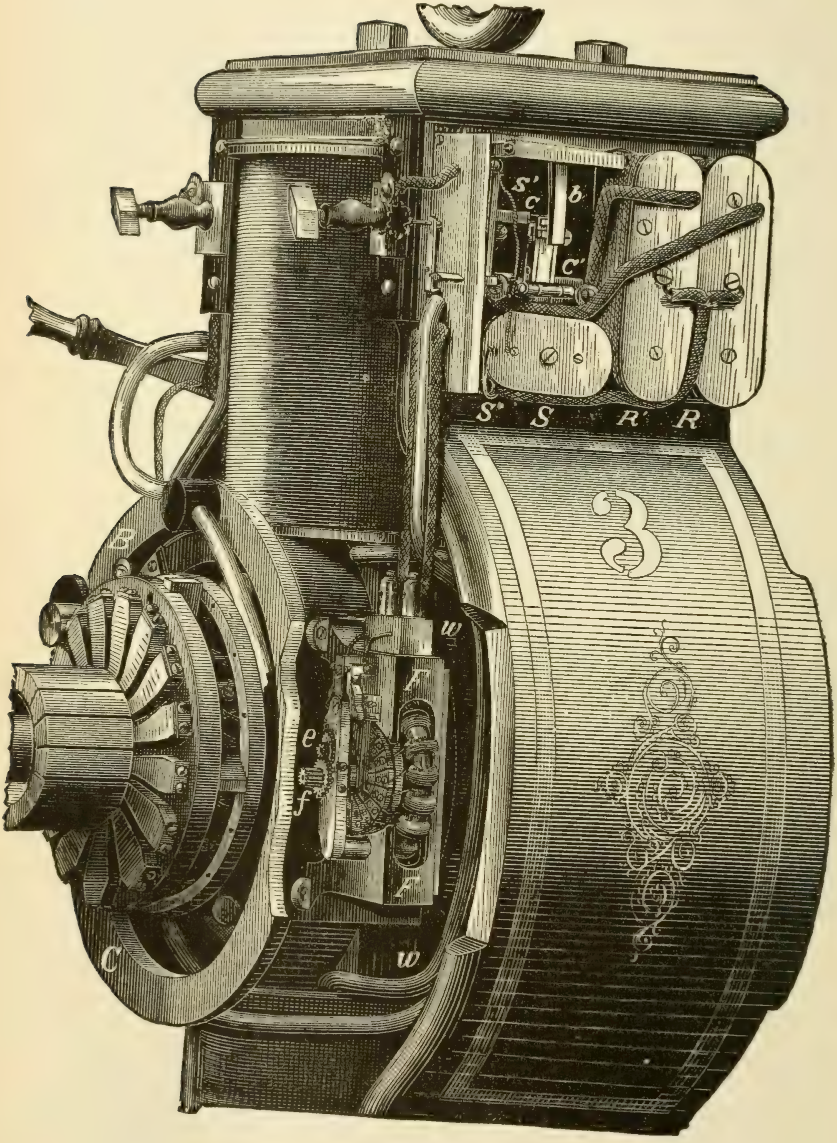


Fig. 429.

internal resistance of this type of machine is 30 ohms, measured at rest between the binding posts. When supplying 25 arc lights through an average circuit, it develops an electromotive force of about 1,250 volts and a current of 10 ampères.

The device for holding the brushes and moving them backward or forward as required, consists of a large brass ring, B C, fig. 429, held in place by four rollers, *r r r r* (fig. 430), screwed into the pole pieces. This ring, therefore, moves concentrically with the commutator, and when it is moved, the position of the brushes, B B (fig. 430), is varied. When the position is to be regulated by hand, a suitable insulated handle is attached to this ring; but when the regulation is accomplished automatically, the ring is provided with fine gear for a portion of its circumference at the right hand side, as shown in fig. 424.

Each brush holder is double, so that there are two brushes on each side of the commutator. These brushes do not touch the commutator side by side, but one is placed a little in advance of the other, the space between being equal to about one segment. The function of the second brush thus electrically connected to the regular brush is to short circuit, for an instant, each section in turn just as it passes the neutral point in the magnetic field. It is well known that each section of wire in a Gramme armature, while it is passing over the neutral point, constitutes an idle resistance for a moment in each revolution, at which time it is not contributing its share to the current. The use of the two brushes is to short circuit this idle section and thus reduce the internal resistance. A switch is used to put the current on the external circuit or take it off without giving rise to injurious sparks, a diagram of which is shown at the left in fig. 430. The principle of this switch is simply to short circuit the armature, and cut off the current from the field magnets before the external circuit is broken. For this purpose the two metallic contacts, *d d*, are brought near enough so that the switch A may touch them both together when at S. If the switch were turned the other way, the external circuit would be closed. As it stands, the external circuit is opened and the armature short circuited.

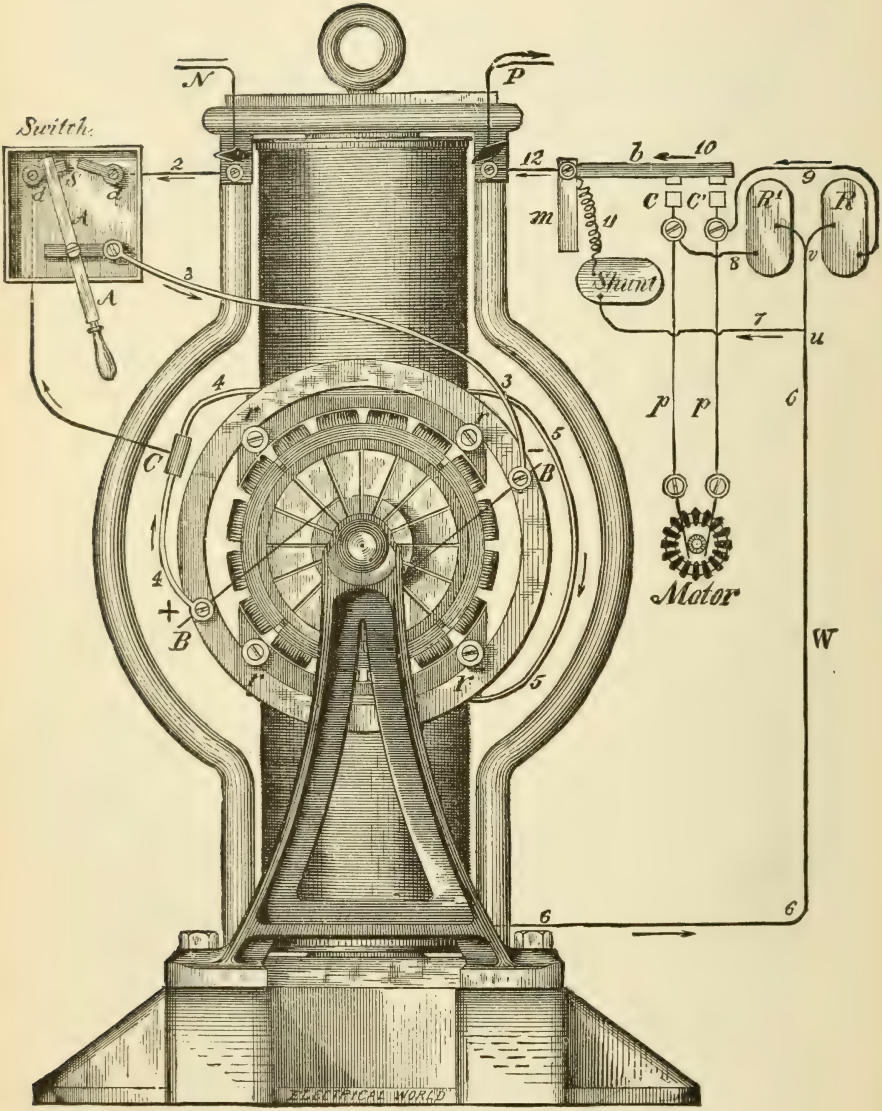

N
P
Switch.
S
d
d
A
A
2
12
b
10
c
C'
9
R1
R
m
11
8
v
Shunt
3
7
u
4
3
5
C
–
B
r
r
p
p
6
4
+
B
Motor
W
r
r
5
6
6
ELECTRICAL WORLD

Fig. 430.

THE REGULATOR.

It is very desirable that the supply of current should remain constant in an arc light circuit, and it is also desirable that the power consumed should diminish when some lights are cut out of the circuit, and for this reason it is necessary to have recourse to regulating methods. About the easiest is to move the brushes away from the neutral point when less current is required. By this operation some of the sections are commutated on the wrong side, and thus counteract the induction produced, so that the

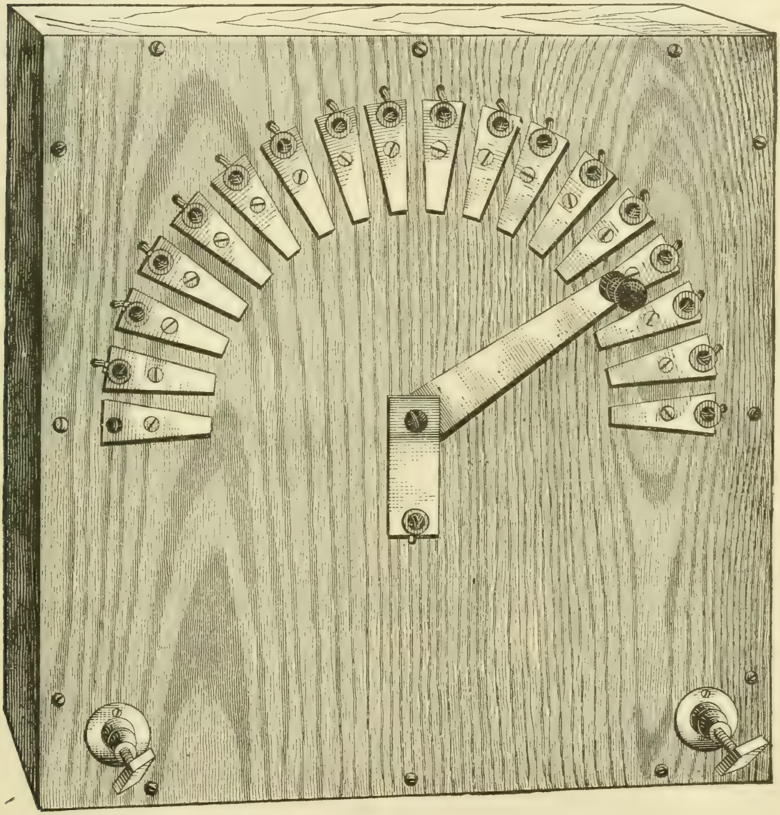


Fig. 431.

available electro-motive force is lowered and the current in the circuit decreased. If the brushes are moved back 90 degrees from their normal position, no currents will be collected, as half of the sections will be commutated wrongly on both sides, and will exactly neutralize the induction in the others. Thus it is possible to so adjust the brushes that any desired current may be produced. When the decrease required is very small, say one or two lights in a circuit of ten, this method is satisfactory enough, and the reduction in power required to drive the generator, though not so low as with other means of regulation, is yet nearly proportional to the decrease. But when the variation is greater, the regulation is not so economical. However, as the majority of cases only need a small range of regulation, this method answers very well, and Mr. Hochhausen has applied it to his machine in a very satisfactory manner. The brush-holder ring is geared on a portion of its circumference, and a pinion, *f*, (fig. 429), turned by a small electro-magnetic motor, engages these gears, causing the ring to turn, and with it the brushes. This miniature motor consists of a ring armature revolving between two field pieces, F F (fig. 429), which are bolted to the upper and lower pole pieces respectively, and derive their magnetism from them. The speed is reduced by a large wheel, *e*, which moves a small pinion, geared with a larger wheel controlling pinion *f*. The geared portion of the ring B C is removed in this figure.

The regulation is effected by a device which, when the current in the main circuit is too strong, causes the motor to turn so as to displace the brushes, or causes it to move the other way so as to give them greater lead when the current is too weak. This controlling device consists of the field magnet, which, acting upon an armature, controls the connections of the motor circuit. As long as the strength of current remains constant, the power of the field magnet remains the same, but the instant the current varies, the power of the field magnet changes, and an armature placed in proximity to it detects these changes.

The apparatus controlling the motor and brush is enclosed in the box at the top of figs. 424 and 429; in the latter case, with the cover of the box removed. The armature is pivoted horizontally, and is connected directly with the right binding post, branch *s′* being given off at this connection, however, to a shunt, *s″*, as more clearly shown in fig. 430, in which *m* is the armature here shown vertically for convenience. Attached to the armature *m* is a small vertical metallic bar, *b* (fig. 429), which, when the normal amount of attraction is exerted upon the armature, presses equally on two contacts, *c c′*, from which wires 8, 9 (fig. 430) lead to shunts, R^1 R, and from which wires, *p p*, also lead to the motor.

Fig. 430, which represents an elevation of the commutator end of the Hochhausen generator, also shows the connections of the field magnets and armature as made in the series-wound machines for arc lighting.

Beginning at the negative binding post N, and following the circuit by the wires 2, 3, etc., we come to W, which at *u* gives off a branch (7) that goes to the shunt and past the motor. At *v* this line divides into two circuits through R′ and R, through 8 and 9, to *c c′*, to *b*, to 12, to P. Both sides of the motor are of the same potential, and consequently it does not move. If the current in the main circuit falls, then the retracting spring controlling the armature *m* (the tension of this spring being adjustable by a screw shown in fig. 429), will cause the armature to fall back, and thus *b* will be tilted until it leaves contact with *c′*. In this condition we find, on following the circuit from *v*, that the current is passing partly through R, 9, *c′*, to *c*, through the motor which would be set in motion, and partly through R′, through 8 to *c*. If there were no resistance in the coil R′, then the motor would be short circuited. As it is, the motor receives a current due to the difference of potential between the two ends of R^1. On the other hand, if the current in the main circuit were to have been too strong, the motion of the armature *m* would be such as to tilt *c* out of contact. On following the circuit from *v* now, it would be partly to R′, 8, through the motor to *c′*, to *b*, and partly through R, 9, to *c′*, and the motor would move in an opposite direction.

It is seen that one of the branches from *v* always shunts a greater portion of the current past the motor. But the branch 11 to *v* itself does not receive all the current, a portion being shunted past through the branch 7, to shunt coil to 11. The latter shunt could be dispensed with, since there is always one of the contacts *c′ c* completing the circuit, but its use insures the continuity of the circuit in case of derangement of the contact arm *b*, or from any other cause. Moreover, with this shunt, the sparks produced when the platinum points *c′ c* leave contact are prevented. It will also be understood that by regulating the resistance of this shunt the amount of current diverted through the motor branches, and consequently the speed of the motor may be regulated.

Although this regulation is intended specially for use on series-wound machines for arc lighting, Mr. Hochhausen also applies it with success to machines of the same construction, but shunt-wound, manufactured for incandescent lighting. In this case the control of the motor cannot be effected by an armature subjected to the attractive influence of the field magnet, whose strength increases inversely with the current in the external circuit instead of directly. A separate magnet is therefore used. Besides this, the regulation of the current in shunt-wound machines is also provided for by means of a hand regulator (fig. 431), by means of which the amount of resistance introduced in the field magnet circuit is varied.

The resistance coils are looped between the contact segments, which are arranged in a circle, and form one continuous circuit. Connections are made from one binding post to the first segment on one side and from the other binding post to the switch lever. Thus, supposing the right-hand binding post to connect with the first segment at the right, and the left-hand one to connect with the switch lever, then, as the switch stands, there are three of the resistance coils included in the field magnet circuit. In one of the shunt-wound machines, the switch lever of the field resistance regulator was attached by way of experiment to the brush-holding ring, and thus the same movement sufficed to adjust the brushes and regulate the resistance in the field magnet.

Mr. Hochhausen has devised a very simple form of ampère metre for use with the arc light machine, in order to enable the attendant to determine readily the amount of current in circuit and see how perfectly the regulation of the supply of current is effected. The current is made to pass up or down through a flat strip of copper placed between two magnetic needles swinging on the same pivot, and weighted so as to maintain a vertical

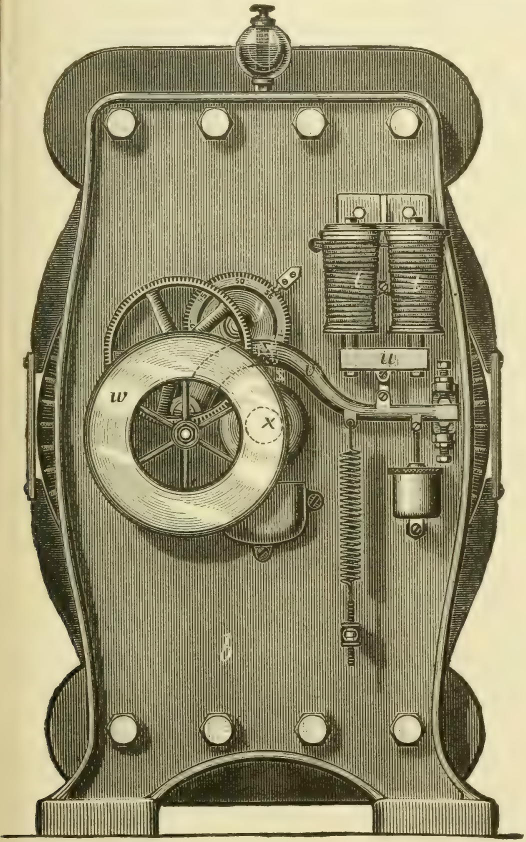


Fig. **432.**

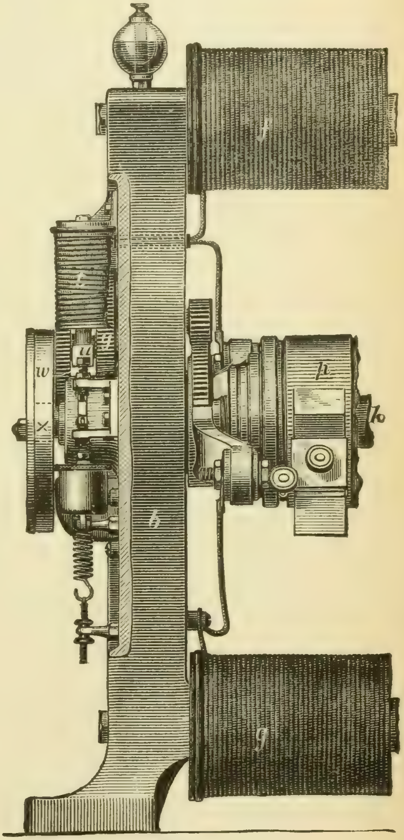


Fig. **433**

position when no current is passing. The two needles are magnetized to the same power, but their poles are relatively opposed, so as to make an astatic combination. This eliminates the action of the earth's magnetism, and also any other disturbing magnetic influence. The scale is graduated in ampères by actual comparison with a standard.

The Hochhausen machines are made in six types. No. 1 series wound produces one light of 2,000 candles. No. 5 series wound supplies 25 arc lights of 2,000 candles (nominal), and shunt wound 250 incandescent lamps. The speed of the latter machine is 750 revolutions per minute.

WOOD'S AUTOMATIC CURRENT REGULATOR.

This apparatus, which is manufactured by the Fuller Electrical Company, of New York, is intended to regulate the current of dynamo-electric machines constructed for arc lighting. The object is to provide a means of automatically reducing the current in circuit when one or more lights are extinguished, and automatically increasing it when the lamps are again interposed. Fig. 432 represents a front elevation, and fig. 433 a side view, with a portion of the frame *e* broken away. The operation of this apparatus is as follows: The electro-magnet *t t*, seen on the side *e* of the generator, which is interposed in the main circuit, attracts an armature, *u*, this attraction being opposed by a spring, the movement of which is retarded by a dash-pot. In case one or more lights are turned off, and the resistance of the circuit thereby decreased, the electro magnet *t t* becomes more strongly energized, attracting its armature *u*, which, through the agency of the lever *v*, presses the inside rim of the friction wheel *w* against the roller *x*, that is on the end of the armature shaft *k*, which, by means of gearing, causes the brushes to be moved toward the minimum point, until there has been a sufficient reduction in the strength of the current, and consequently in the attractive force of the electro-magnet *t t*, to allow the spring to again pull the lever to its intermediate position. In case one or more lamps are turned on, the resistance of the circuit will be increased, the strength of the electro-magnet *t t* will be proportionately diminished, and the spring, acting in opposition to it, will press the outside rim of the friction wheel *w* against the roller *x*, causing the brushes to move toward the maximum point, until the current and also the electro-magnet *t t* again assume their normal strength. When all the lights are turned on and the machine is running at its proper speed, the brushes will assume their maximum position. In case the speed of the machine should be diminished while the full number of lights are burning, thus reducing the current, the regulator would automatically tend to move the brushes to a position beyond the maximum point in its endeavor to maintain the current required to operate the full number of lamps. As the brushes cannot be moved further than to the maximum point, the electro-magnet *t t* would diminish in strength, increasing the friction and tending to wear the wheel *w* at the point of contact with the roller *x*. To prevent this, the wheel *y*, that gears directly with the sector of the yoke holding the brushes, is so proportioned that it only makes $\frac{7}{8}$ of a revolution in moving the brushes from the maximum to the minimum point. It has a pin, *z*, on its side, which engages with a projection, z', on the lever *v*, raising it so as to automatically relieve the pressure from the friction wheels *w x*, thus obviating the tendency to wear. Another advantage that the regulator has over others is that the wheel *y* is graduated around its periphery so as to represent the number of lights the machine is intended to operate. As this wheel assumes a position depending entirely on the number of lights in circuit, the figures on the rim act as an index to inform the engineer of the number of lights his machine is operating. In case several lights are extinguished at once, the electro-magnets are energized to a considerable extent beyond their maximum power, increasing the pressure proportionately on the friction wheels and causing them to move very much faster than would be the case if but one or two lamps were extinguished. It will also be seen that the inside rim of the friction wheel *w* is only about one-half the diameter of the outside rim. The advantage of this construction is twofold; *first*, the inner rim, which is the smallest, moves the brushes toward the minimum point in a direction in which the commutator is revolving, requiring the least power, as the friction of the brushes on the commutator assists it, while the outer rim, which has the greatest leverage, moves the brushes in a direction opposite to that in which the commutator is revolving, requiring the most power, and moves more slowly to the maximum point; and *second*, as it is essential that the extra current be turned off as rapidly as possible when lights are extinguished, and when lamps are put in circuit that the current be turned on more slowly so as to prevent sparking. This object is exactly attained by the apparatus described. The regulator is so instantly effective in its operation that from one to the full number of lights on a fifty-light dynamo may be turned off at once without endangering the safety of the machine.

Mr. Wood has also designed an electro-magnetic apparatus for use in connection with the automatic current regulator, which is placed in the main circuit, and connected with the current regulator in such a manner as to automatically shunt more or less of the current from the electro-magnet *t t*. The object of this apparatus is to increase the sensitiveness of the regulator, so that the slightest change in the strength of the current will cause a far greater change in the strength of the regulator magnet *t t*, making its operation in one direction or the other more rapid.

COLBURN'S MACHINE.

Fig. 434 represents the Colburn dynamo-electric machine for electric lighting. The frame of the machine consists of a strong iron case with the cores of the field-magnets inclined toward the centre, all cast in one piece. The arrangement of the field-magnets is such that the armature is constantly in a

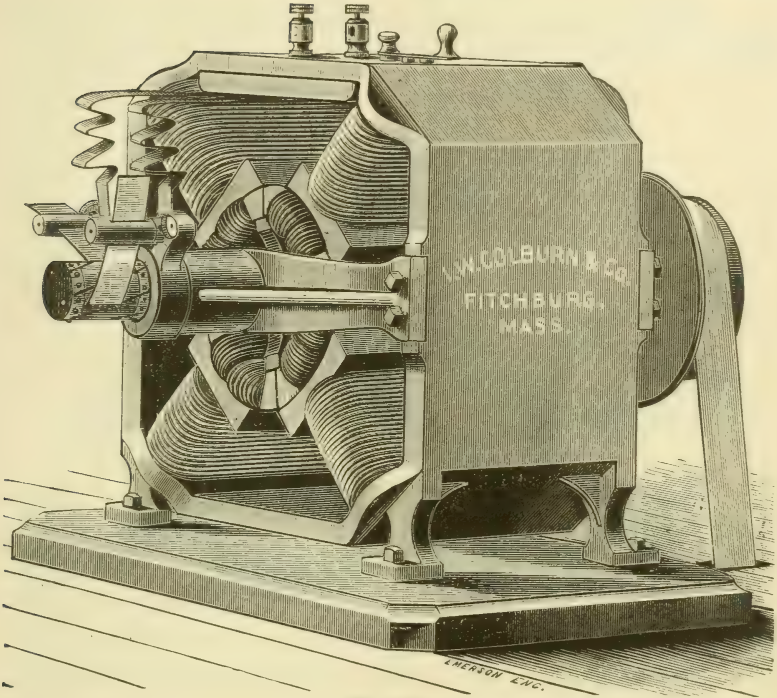

I.W.COLBURN & Co.
FITCHBURG.
MASS.
EMERSON ENG.

Fig. 434.

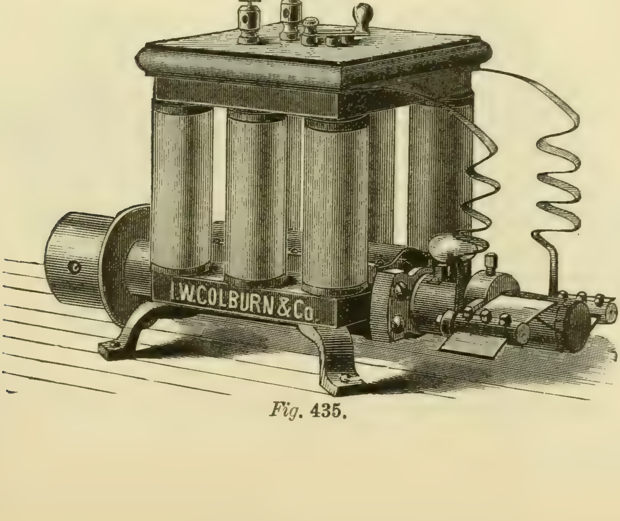

I.W.COLBURN & Co.

Fig. 435.

strong magnetic field. Fig. 435 represents a form of electroplating machine in which the cores of the field-magnets are

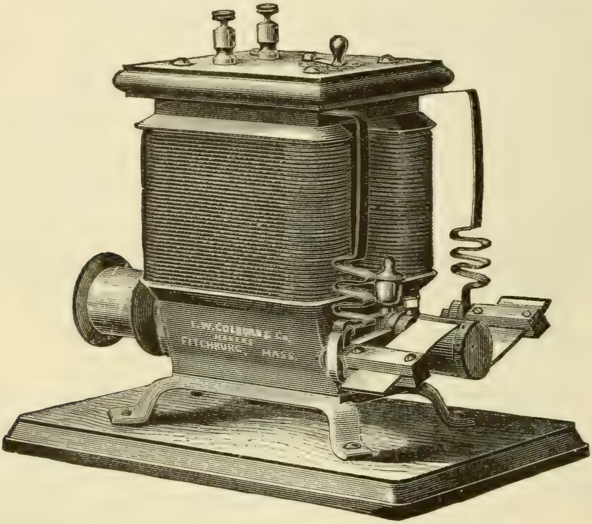

I.W.COLBURN & Co.
MAKERS
FITCHBURG MASS.

Fig. 436.

made of wrought iron, and fig. 436 represents another form in

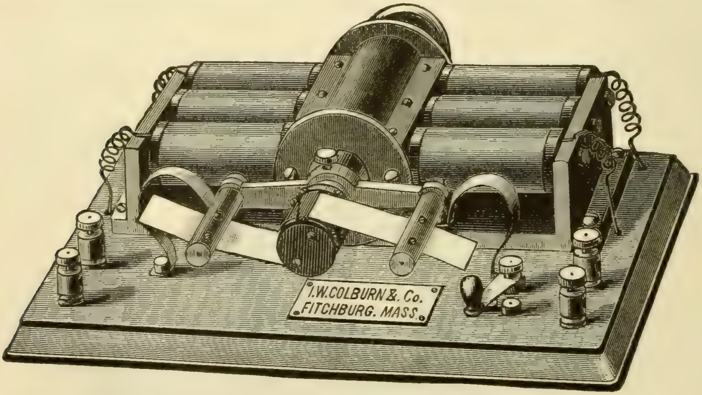

I.W.COLBURN &. Co.
FITCHBURG. MASS.

Fig. **437.**

which they are made of malleable cast-iron. Fig. 437 represents a machine designed for experimental purposes, and for use in schools and colleges. Fig. 438 shows a form of generator

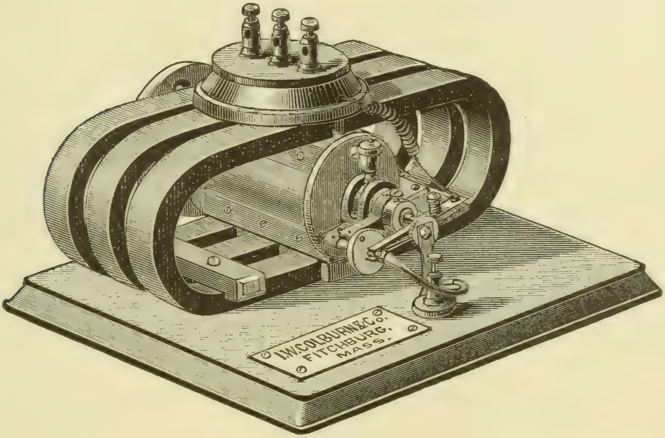


Fig. **438.**

designed for telephone exchange use, for ringing bells and dropping annunciators; and is said to be capable of satisfactorily working the longest trunk lines.

THE CABELLA ARMATURE.

The axle of the Cabella armature is covered with an insulating coating, in which are fixed, in suitable grooves, numerous little plates of copper cut from a sheet of $\frac{1}{25}$ of an inch in thickness, in the form of a rectangular merimeter wanting one of its greater sides. In one of these armatures there are 300 plates of the form indicated, having a uniform breadth of $1\frac{1}{4}$ inches. These are held in their place by wedges of vulcanite compressed between the successive plates. The system of spirals of copper around the iron core forms a continuous spiral precisely as in Pacinotti's ring, and the entire resistance is very small. The advantages offered by the Cabella armature are, besides the smallness of its resistance, its solid and compact structure, which renders its disarrangement by centrifugal force difficult, and permits the convex surface to be approximated to within $\frac{1}{25}$ of an inch of the internal sides of the cavity. One of these armatures, of the diameter of two inches, has been recently substituted for the Edison armature in the cavity of its inductor in an Edison Z machine, used to feed 60 Edison A lamps, that is to say, of 16 candle power each. On giving a speed of 1,050 revolutions per minute, there was obtained a current sufficiently intense to keep burning with a beautiful clearness 150 of such lamps, arranged in 15 derivations, with ten lamps in parallel series in each. This result has been repeatedly obtained in trials, at which competent judges have been present by invitation, and who are of opinion that the armature constitutes a very notable progress in the construction of induction machines, and, consequently, in the production of the electric light.

LUMLEY'S MACHINE.

The armature of the Lumley machine is built up of a number of disks punched from thin plates of the best charcoal iron. The interval spokes or teeth of these plates are let into a gun-metal frame attached to the steel spindle, and each plate is separated from its neighbors by a brass ring. The armature is then firmly attached to the axle, by collars and nuts. It is then coiled with wire, wound in such a manner as to bring both ends of the coil upon the outer surface of the wire. The ends of the coils, 18 in number, are passed through a metal collar or sleeve which acts as a bearing at one end of the machine, and are then inserted into holes in the commutator bars, which are slit through, the ends being then firmly screwed down, thus holding the wires tight. This is a convenient and simple way of attaching the coils to the commutator. The field-magnets are of an ordinary shape, the cores being of cast-iron and forming part of the frame. In each pole-piece is an opening for the purpose of ventilation. The special construction of the armature is also favorable for keeping it cool. The length of the armature is 9 inches; outside diameter $8\frac{3}{4}$ inches; number of sections of wire, 18; resistance of armature, shunt machine,

.079 ohms; series machine, about 1 ohm. The resistance of electro-magnets, shunt machine, 7.8 ohms; series machine, about 1 ohm. The electro-motive force of the former at the terminals, when driven at about 1,680 revolutions per minute, is 46.25 volts, and the current 74.2 ampères, the machine being adapted for 68 Swan lamps of 20 candle power each. The size of the machine is 2 feet 9 inches × 2 feet 5 inches × 1 foot 2 inches, and the total weight 4½ cwt. The chief advantages claimed for the Lumley machine are good ventilation, absence of Foucault currents and great strength of armature, enabling it to be safely driven at high speed, and cheapness.

CHERTEMPS AND DANDEU ALTERNATING CURRENT MACHINE.

This machine consists of two series of six coils each arranged on the end plates, constituting the inductor; a series of six other coils arranged on a plate between constitute the induced part, which is stationary; the plates with the inducing coils revolve. The machine is self exciting—the exciting current being obtained from one of its induced coils, the current of which is made to flow in one direction. For this purpose the current of one of the coils is brought to the brushes and passes into the inducing coils, passing through a commutator which at each moment sends it in the direction required. In order to render combinations of circuits possible at every moment, the circuit of each induced coil is brought separately to two terminals on the upper plate of the machine, where it can be employed either separately or in combination with the others. A piece of metal forming a slide facilitates these combinations. Each of these circuits at starting passes into two little coils furnished with an armature which, when lowered, unites the two poles of the circuit of the coil. The result of this arrangement is, that when a coil is not furnished with an outer circuit through which a current passes, the armature connects the two poles and closes the circuit; as soon as an outer circuit is formed the electro-magnet acts and raises its armature, so that the outer circuit alone remains and receives all the current. This is necessary because the alternating machines of this type, unlike the continuous ones, require less force when the circuit offers less resistance. In these systems if the circuit is broken, the machines immediately absorb a great deal of force which they transform into heat in the iron cores of the coils; it is desirable, therefore, that such an occurrence should be impossible, and that the circuit should be automatically closed upon itself if it happened to be opened externally; this is the advantage of the Chertemps and Dandeu apparatus. This machine, like the Gramme, easily produces the high tensions generally required from an apparatus of the kind; it is coiled with wires of somewhat small diameter and of rather high resistance, being constructed to act at long distances. Experiment shows that the force absorbed increases almost in proportion to the electrical work produced, which is advantageous for the full utilization of the motors. The machine is very compact and of small dimensions, and when revolving at a speed of 1,300 revolutions, 10 Jablochkoff candles were lit and maintained in steady action.

WESTON'S DYNAMO ELECTRIC MACHINE.

Mr. Edward Weston has for many years been known as an ingenious and successful inventor, designer and constructor of dynamo-electric generators, both for electro-plating and electric lighting. In fact the greater portion of electro-plating in all parts of the world is now done by Weston machines. Mr. Weston's dynamos of both classes have gained a wide reputation for their compactness, excellent mechanical construction and durability, as well as for their electrical efficiency. For these reasons it has been thought desirable to give a somewhat extended account of his work in this line, and to illustrate some of the typical forms which have been developed by him from time to time, for although the Weston machines of different classes present certain resemblances in detail to the machines of Lontin, Siemens, Gramme and others, they nevertheless contain many other features of distinct and positive originality.

As early as 1872, Mr. Weston, who was then engaged in the general business of electro-plating in New York City, finding that the results of the operation of the different dynamo-electric generators then available in the market, as observed by him in daily use, were not satisfactory, undertook to construct a machine to be used for the ordinary requirements of his business. This first machine was essentially of the Gramme type, but it contained some modifications which served to increase its efficiency in the execution of the particular work to be performed by it. During the following year he constructed another machine which was essentially a Ladd generator, the field of force being maintained in the main field coils by the action of an independent armature. Both these machines did very good service in comparison with others then in use, although much difficulty was experienced from the development of heat in the armature, which was a common fault with all machines of this class at that date. In 1873 and 1874 Mr. Weston tried still another form, which, in all essential respects, was a modified Siemens machine, the most important change being in the particular construction of the armature, in which the sectional principle was introduced. This was done in order to interrupt and break up the so-called Foucault currents, the circulation of which within the mass of the armature is the principal cause of the development of the excessive heat which had been so troublesome in the machines before in use. As Mr. Weston was not, at this time, in a position to afford the expense of making dies for stamping out wrought iron sections of the proper form, he resorted to the expedient of making the armature of soft cast iron, in the well known form of the Siemens I armature, and then forming deep transverse grooves in it at short distances apart, these grooves being, of course, at right angles to the direction of the wire wound upon the armature, and to the direction of the Foucault currents. Very satisfactory results were realized by these machines, of which four of medium size were constructed during the years 1873 and 1874, one of them being used in nickel-plating in his own establishment.

About this time Mr. Weston concluded to dispose of his plating business, and determined to devote his attention exclusively to the manufacture of dynamo-electric machines for electroplating purposes, as it was evident that there was a great demand for a better class of machines for this work than had hitherto been available. With this view he associated himself with the firm of Stevens, Roberts & Havell, of Newark, New Jersey, and commenced a course of experiment and investigation with a view of developing a compact, efficient and low-priced generator especially adapted for the purpose in view. Among other experimental machines constructed at this time, it may be of interest to mention one which embodied the essential characteristics, and in fact was a prototype of a machine which has since attracted a good deal of attention. In this machine the armature comprised a cylindrical wooden drum fixed upon the revolving shaft, upon which a series of iron rings were placed side by side, throughout its whole length, separated from each other by layers of paper. A copper disk was placed at one end of the drum and the longitudinal wires were soldered to this disk. A spiral commutator, the sections of which were so arranged as to have an obliquity of nearly half its circumference, was made use of. This was found to be an excellent machine so far as its performance was concerned, but was, necessarily, too costly in its construction to serve the purpose then in view. The course of experiments which has been referred to finally resulted, in 1875, in the production of the well known Weston electro-plating machine. As this generator is not well adapted for lighting purposes, it is not deemed necessary to give a detailed description of it in this place, but only to refer to it so far as it forms a link in the chain of circumstances which led to the ultimate development of the more recent electric light generators of the same inventor.

The external appearance of the Weston plating machine is well represented in figure 439. Internally it consists of a group of revolving armatures projecting radially, at equal distances, from a hub, the poles of which armature rotate in front of the poles of an equal number of stationary electro-magnets, also radially arranged. The last named electro-magnets are affixed to and project convergently from the interior of the cylindrical iron shell, G (figure 439), being secured thereto by bolts as shown. The shaft, E, which passes through the centre of the cylindrical portion of the machine, carries at one end a pulley which is driven by a belt, D, and upon the other end a sectional commutator, F, with two brushes or collectors, I I. In this machine both the armature and field magnets are in a single circuit, to the terminals of which the flat copper conducting strips, A A, are attached.

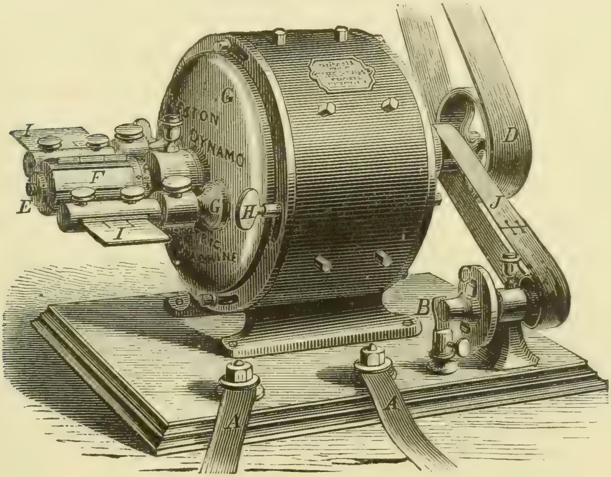


Fig. 439.

This has proved to be in practice a very cheap, durable and efficient machine, especially as its parts when worn or injured may be easily and cheaply replaced without special skill. The manifold advantages which it presented over the older forms were so well appreciated by electro-platers, that it has had an extensive sale not only in the United States and Europe, but in almost every part of the civilized world. It was, in fact, the first dynamo-electro machine of any kind which may have been said to have been entirely successful in a commercial point of view. It received awards at the Centennial Exhibition in 1876, and at the Paris Exhibition in 1878.

A special feature which has contributed largely to the success of this machine is the automatic centrifugal governor or regulator, an ingenious device by which the reverse current due to the polarization in the electro-plating bath is prevented from entering and reversing the polarity of the machine, in case it is stopped after having been some time in operation. The disastrous effects of such a reversal to the articles in course of being plated, had been a very serious objection to the use of dynamo-electric machines for that purpose, especially when intrusted to the hands of unskilled or careless workmen.

In or about the year 1875, the subject of electric lighting by means of currents from dynamo-electric machines began to excite interest, and a considerable degree of attention was paid to the subject by different inventors both in Europe and in the United States. Mr. Weston early foresaw the important results that were likely to flow from this development of the dynamo-electric machine, and as the electro-plating generator to which we have referred was not suitable for such purposes, it became necessary to enter upon a new course of investigation, with a view of producing a machine especially adapted for producing the arc light. Among the early experimental machines for this purpose constructed by Mr. Weston was one having an armature of the Pacinotti, better known as the Gramme type, and another which was essentially a modification of the Romilly machine, in which the armature was made up of separate rings, capable of being independently wound and afterwards connected together. Several other machines were made in 1876, essentially of the type since brought out in Europe as the Meritens. One of these was used as an electric motor, for propelling a torpedo boat which was constructed for the United States Navy Department in 1879, and another similar one was furnished to the department in 1880. The efficiency of these motors, which were of about six horse power, is shown by the fact that a speed of 12.4 miles per hour was actually attained in trials made by the officers of the government at different times.

Another form of generator, presenting a number of features of special interest, was devised and constructed by Mr. Weston in 1877, in which the armature coil was wound upon a hollow drum or carrier of non-magnetic material (*papier mache* being the material preferred in practice), and this armature coil was made to rotate in a magnetic field between the poles of two stationary field magnets, and also around a stationary electro-magnet situated within the hollow carrier. This carrier was in the form of a cylinder, and was provided with perforations at its ends and in its periphery, thus making use of the centrifugal force due to the rapid rotation of the coil to establish currents of air, the air being drawn into the carrier through the perforations at the ends and expelled tangentially from the perforations in the periphery, thus dissipating the greater part of the heat generated in the machine when in operation. This will be recognized as the operative principle of the well known centrifugal fan or blower. Its application to the rotating armature, whereby the latter is itself made to form a fan or blower, for preventing the working parts of the machine from becoming overheated, is certainly a very novel and ingenious one. In this machine the pole pieces were also divided into sections by deep grooves cut entirely through them, in a direction at right angles to the axis of the revolving armature. The external or field magnets, the rotating armature coils and the stationary magnet within the armature coils were all connected together in a single circuit. By a modification of the circuit connections of this machine, two wholly distinct external circuits may be formed.

In this connection it should be mentioned that an independent fan blower had already been used by Mr. Weston for the same purpose, having been applied by him to a large plating machine as early as 1876.

The generator which has been described was found to be a most efficient and excellent machine, so far as its performance was concerned, but the expense of its construction was so great in proportion to its capacity that efforts were continued in the hope that an equally efficient machine of less costly construction might be devised. Experiments with this generator, in which the wire of the armature moved while the core remained stationary, showed that it was as necessary to divide the iron armature into sections as when the whole mass was rotated.

In 1877 Mr. Weston also brought out his sectional disk armature, which has since formed, perhaps, the principal distinguishing characteristic of the machine built by him for lighting purposes. Fig. 440 is a perspective view, showing the appearance of the body of this armature after the several separate disks have been assembled together and mounted upon the axis, in readiness to receive the conducting wire. It will be seen that each disk is provided with a number of projections upon its periphery, giving it the general outline of a cog wheel. These projections serve to separate the groups of coils from each other, and also, when assembled, form the exterior poles of the armature. Each disk is perforated with holes for admitting air from the ends of the armature into narrow openings or spaces which are left between the disks. By this means the mass of iron which forms the armature is subdivided into so many separate masses that the establishment of induction currents within it is effectually prevented. Each one of these disks is slit radially at one point in its periphery, in order to prevent the formation of a rotary induction current within the disk itself. The particular construction of this armature, as now made, will

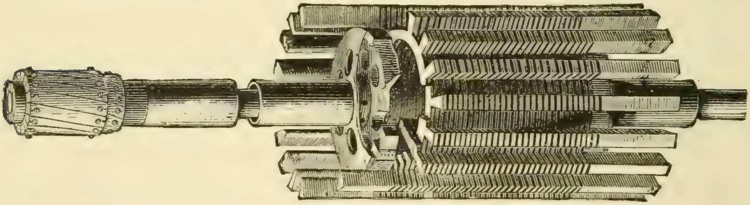


Fig. 440.

be more fully described hereafter in connection with some of the more recent forms of the Weston machine. The method of winding employed in this armature was quite similar to that of the well known Siemens or Alteneck armature; that is to say, the wire passes longitudinally along one of the grooves parallel to the axis and across one end, returning by the corresponding and diametrically opposite groove on the other side.

The peculiar form of commutator used upon the Weston machine at this time is well shown in figs. 440 and 441. Generally speaking it is similar to the commutators of the Siemens and Gramme machines, but it differs materially from these in construction by virtue of the fact that the separate insulated segments of which it is composed are arranged helically on the shaft, and are separated merely by air-spaces, and not by solid insulating materials. By reason of this peculiar disposition of the commutator segments, the rubbing edges of the collectors or brushes are always in contact with two segments of the commutator, whatever may be the angular position of the armature. By this means greater uniformity in the strength of the current is secured.

At an early period Mr. Weston adopted a peculiar form of collectors or brushes, which he has since continued to use. These are made up of ten or twelve thin curved sheets or plates of rolled copper, slit at the ends so as to form three parallel fingers, and held against the commutator at such an angle that the edges of each individual sheet of the whole bundle pressed against the surface of the rotating commutator. The collectors are mounted upon a movable support in such a manner that the strength of the current and of the magnetic field may be adjusted within certain limits to the work to be done, by varying the angular position of the collectors, so as to place them by trial in the position of maximum efficiency.

During the year 1877 Mr. Weston adopted a special type of generator for lighting purposes. This machine included most of the improvements which have already been described, and its general construction will be understood without difficulty from the perspective view given in figure 441. In this will be seen many of the essential characteristics which have been referred to, such as the sectional armature and sectional pole-pieces, the spiral commutator, and the adjustable brushes. In this machine a change was also made in the electrical connections of the generator. This modification was in accordance with a suggestion originally made by Professor Wheatstone, who, in a communication to the Royal Society, in February, 1867, proposed that instead of the entire current only a portion should be made to traverse the main electro magnet of the dynamo machine for the purpose of maintaining the field of force. The advantage of this construction is, that the machine is rendered much less sensitive to changes in external resistance of the circuit with which it is connected, than when the armature and field are connected in series. When the shunt-wound machine is in action, and a variation in resistance occurs in the external circuit, the machine in a great measure adjusts itself to the changed conditions. If, for example, the resistance increases, the resistance of the field coils necessarily becomes a smaller fraction of the total resistance in circuit, and hence a greater portion of the current is diverted through them. This of course

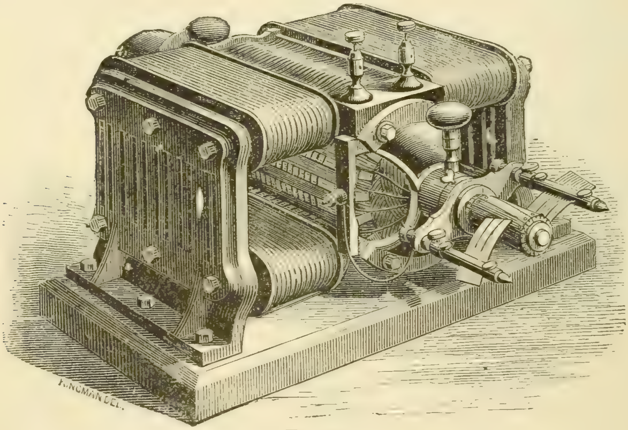


Fig. 441.

intensifies the field and the electro-motive force of the current generated by the revolution of the armature is correspondingly increased, so as to overcome the resistance in the external circuit. On the other hand a diminution of the external resistance causes more current to flow through it and less through the coils of the field magnet. Hence the electro-motive force of the machine is in this case reduced, and the current falls off in a corresponding ratio. An incidental advantage of this method of winding is that dynamos of the same dimensions may readily be wound with wires of different thicknesses, and it therefore presents advantages to the manufacturer, as it enables him to produce machines capable of generating currents differing widely in electro-motive force and volume without changing in any way the essential construction or dimensions of a given type of machine.

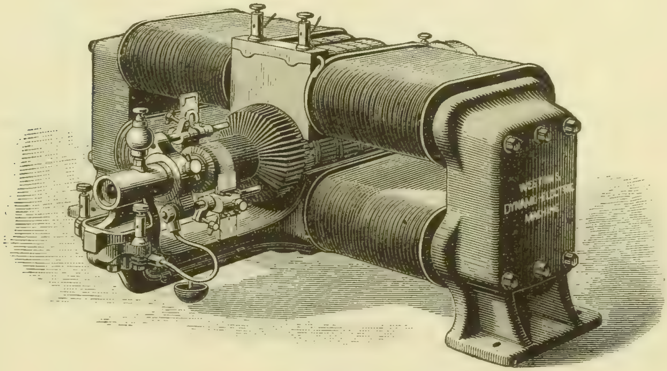


Fig. 442.

Figure 442 is a front, and fig. 443 a rear view in perspective of the earlier machines of the construction which Mr. Weston has finally adopted as a standard. Although the general form of the preceding machine has been retained, it will be noticed that there are some marked changes in the details of construction. The pole pieces are made heavier and are brought somewhat nearer together than before, thus inclosing a greater portion of the circumference of the armature. Instead of a commutator having a small number of sections arranged helically, as in the machine last described, a great number of sections are employed corresponding to an equal number of coils upon the armature, and the commutator segments are made parallel to the axis of the armature in the ordinary manner. This machine was somewhat changed and improved in its mechanical construction, although not essentially altered in its working parts, in the early part of 1881, at which time the present standard Weston machine was first put upon the market.

This machine, which is shown in Figs. 444 and 445, has been very carefully studied, not merely in its general electrical and mechanical design, but in all its details. The general construction and arrangement of the Weston machine of 1879 are retained, but numerous minor modifications and improvements have been made, which add materially to its efficiency. The mechanical design has been much improved in one important respect, by casting the supports for the armature bearings integral with the pole pieces, thus securing the greatest possible strength and rigidity for the frame. At its commutator end the armature bearing is supported only from the lower pole piece, as the strain upon the bearing at that end is comparatively

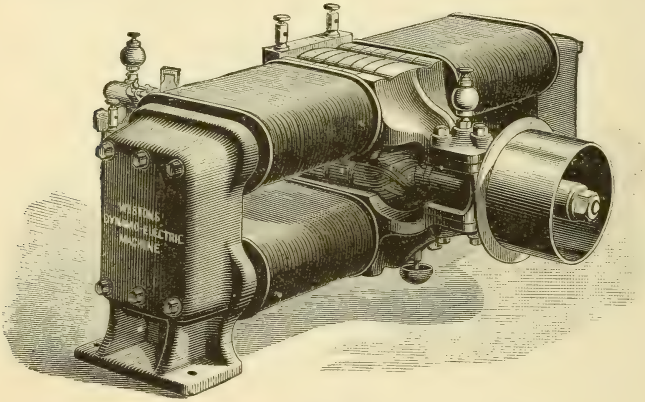


Fig. 443.

small, and this construction enables the commutator to be left open, so as to be readily accessible. The bearing adjacent to the driving pulley is, however, supported by projections from both the upper and lower pole pieces, arranged in the form of an arch, as shown in Fig. 445. As a closed magnetic circuit would be formed between the pole pieces if the projecting supports were brought directly together at the shaft, thus diverting the lines of magnetic force from the armature, a heavy brass bushing surrounding the shaft is interposed between the supports and firmly secured to them by bolts. The general arrangement of the machine, as will be seen from the illustrations, is at once symmetrical and elegant, and in fact the design leaves little to be desired, either from a mechanical or electrical point of view.

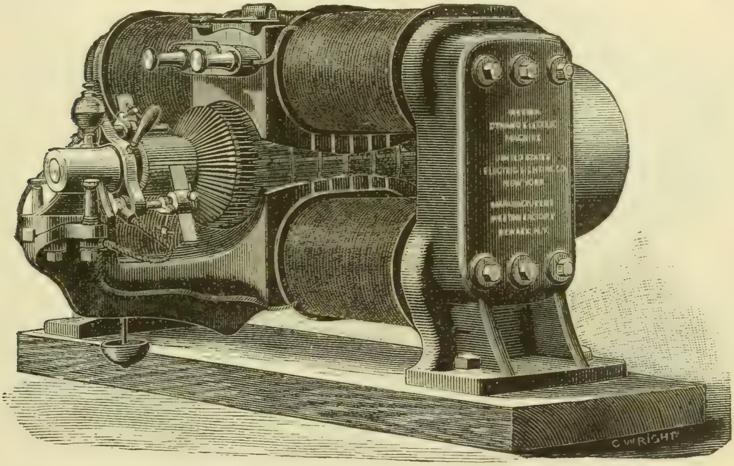


Fig. **444.**

The most important of the distinctive features of the Weston machine is the sectional armature, which has already been referred to, and which is retained in the present machine. The grooves for holding the wire are made of less depth than in the earlier machine, in order to bring the wire of the armature nearer to the pole-pieces of the field magnets, which has been found to increase the efficiency, and the shape of the end pieces has been improved. The armature core is built up of iron disks, as shown in Fig. 446, each disk being of the form shown in the upper part of the same figure, at the left. These are secured together side by side upon the armature shaft, but separated from each other so as to leave narrow spaces between them. These spaces serve not only to break up the continuity of the core and thus prevent the formation of induced currents, but also form the ventilating spaces for the escape of air from the interior of the armature. The armature is made to act as a centrifugal blower, in the manner already explained, in order to maintain a circulation of air through the core and about the coils, which dissipates whatever heat may be generated in them. The armature wires are spread apart, where they pass across the heads of the armature by means of flanged plates (shown somewhat removed from the head of the armature in Fig. 446), so as to leave an opening around the shaft for the admission of air, which passes into the interior of the armature and is expelled through the spaces between the coils by centrifugal force. With a sectional armature and this system of ventilation, no trouble

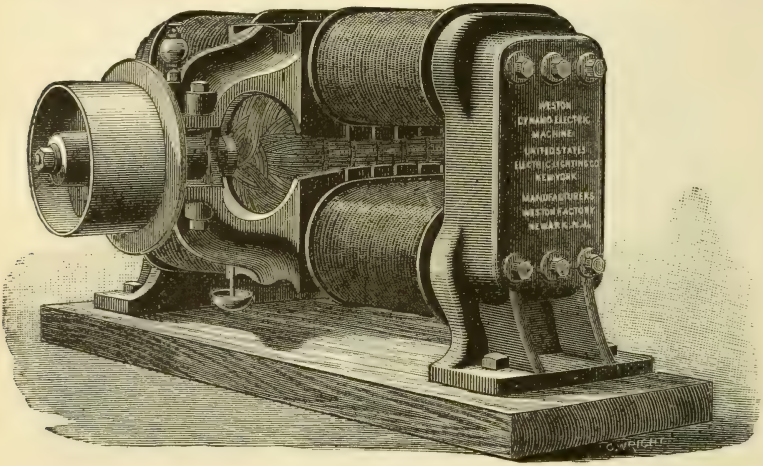


Fig. 445.

whatever is experienced from heating of the core or coils, although the development of heat in machines of this type, having solid armature cores, was formerly so great as to be an almost insuperable obstacle to their use. The armature when complete, with its coils connected to the commutator, is shown in Fig. 447.

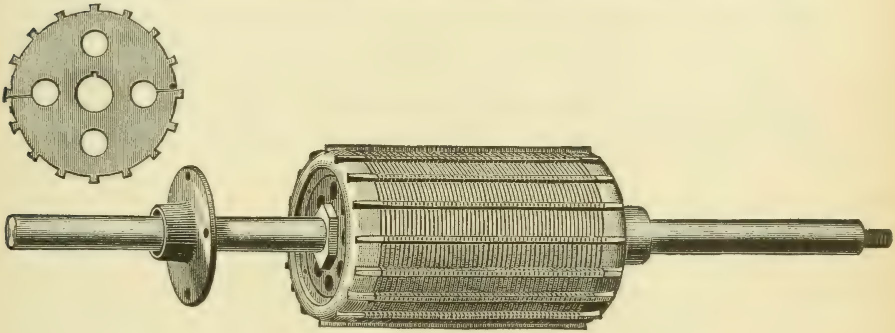


Fig. 446.

The great increase in the number of sections in the commutator reduces the sparking at the brush contacts and prevents the current from discharging across from one brush to the other. The number of sections formerly used was eight; in the present machines, from forty-eight to one hundred and forty are used.

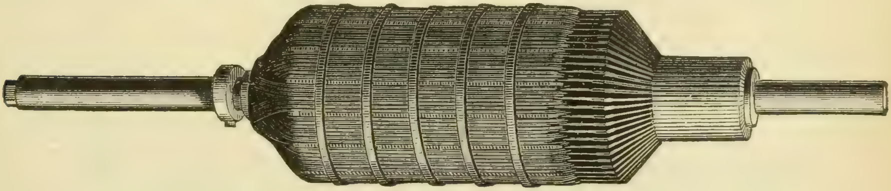


Fig. 447.

As the intensity of the spark at the commutator, as well as the smoothness of the current, depends largely upon the method in which the armature coils are wound and connected to it, Mr. Weston has bestowed much attention upon different systems of winding as applied to cylindrical armatures. The continuous winding of the coils in a single closed circuit, with loops taken out to the successive commutator sections, which was introduced by Gramme, was undoubtedly a very great improvement upon any system which had before been used; but it is obvious that this winding cannot be applied to a cylindrical armature without considerable modification, since in winding coils upon a cylinder, each coil fills up two diametrically opposite spaces, so that the entire surface of the cylinder is covered in winding half way round, while only half as many loops are taken off at the junctions of the coils as there should be sections in the commutator. To overcome this difficulty, Mr. Weston devised the system of winding, of which a diagram is given in fig. 448. For the sake of simplicity, only eight coils are shown in the illustration, but it is obvious that the same principle may be applied to any other even number. If it is assumed for instance, that the winding commences at *a*, the coils follow the course indicated by the full lines, and at each place where the wire passes from one coil to another, a loop is taken off for connection with a corresponding segment of the commutator. After winding four coils, it will be observed that all of the spaces on the armature have been

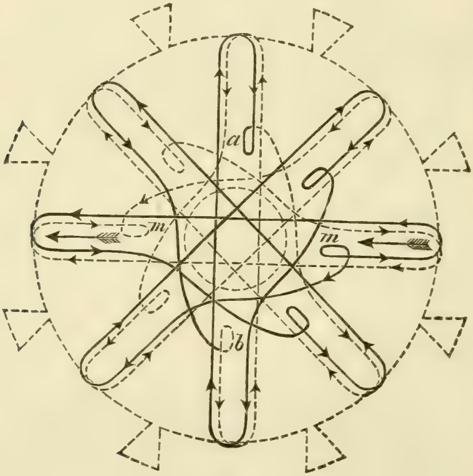


Fig. 448.

occupied, while there are only four loops for attachment to the commutator, while there should be eight. In order, therefore, to supply the remaining four loops, a second set of coils is wound as shown by the broken lines, and additional loops are taken off in the same way until the entire surface of the armature has again been gone over, after which the last terminal of the second set of coils is connected to the entering terminal of the first set at *a*. Supposing now that the brushes are in contact with commutator plates connected with *m m*, the course of the current through the coils may be traced by following the direction indicated by the arrows. If this is done, it will be seen that the current divides and passes through the coils on each side of the dividing line from *m* at the right, to *m* on the other side. If any other pair of diametrically opposite loops be taken, the current will be found to follow a similar course. By covering the entire surface of the armature with the first set of coils, and then again with the second, the second set of coils are superposed upon the first, in a manner which will be understood by reference to fig. 449, which represents a transverse section through

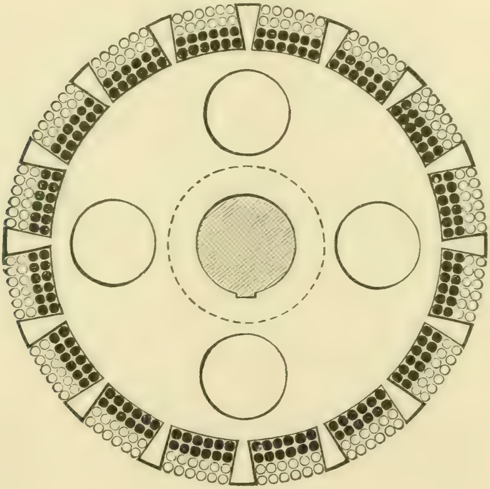


Fig. 449.

the armature. The white circle indicates the wires of the second set of coils, and the black ones those of the first. This arrangement, however, was found objectionable in practice, as the coils of the second set were not only longer than those of the first, but were nearer to the poles of the field magnet, and moved faster on account of being further from the shaft. Hence, the two sets of coils were not electrically balanced, and an objectionable spark was produced at the commutator. This difficulty was overcome by the expedient of winding the coils of the two sets side by side, as shown in the diagram, fig. 450. In this method of winding, each coil occupies the same relative position with reference to the armature core and the field; and a perfect electrical balance is obtained, by reason of which the spark at the commutator is reduced to a minimum. A modification of this method of winding which is shown in diagram in fig. 451, has been found to be more convenient to wind, and in some respects more efficient in its operation. In this, the coils of the two sets are alternately superposed, so that both sets, as a whole, are sub-

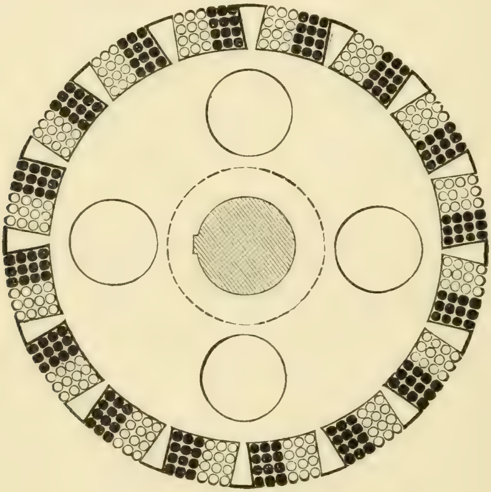


Fig. 450.

jected to precisely the same conditions, and, of course, are electrically balanced. With machines of the improved type when wound in this way, the spark on the commutator is hardly perceptible. In fig. 452, an ingenious mode of connecting the coils to the commutator is shown, which is designed for use in machines of high electro-motive force, such as are used for arc-lighting circuits. In machines having commutators of this general type, the coils are sometimes burned by the accidental short circuiting of two adjacent commutator sections. In the armature represented in figure 452, there are two distinct sets of coils, distinguished by the white and black lines respectively, which alternate throughout the circumference. These are connected to alternate plates of the commutator in the manner shown. It is obviously impossible to short circuit any coil by connecting adjacent sections of the commutator, while the chance of an accidental connection being formed between three consecutive sections is very small.

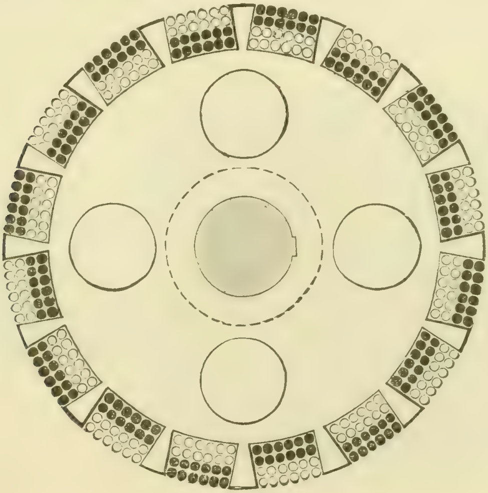


Fig. 451.

The unusual rigidity of the frame, and the great accuracy with which the mechanical work on these machines is done, renders it possible to run the armature with an extremely small clearance between its surface and the pole-pieces of the field. The cores and pole-pieces of the field magnets are made very heavy, so as to maintain an intense field, with comparatively little expenditure of current energy; and the pole projections on the armature bring a part of the magnetic material of the core almost directly into contact with the pole-pieces, so as to concentrate all the lines of force traversing the field directly upon the armature. All of these features of construction contribute to the ability of this machine to produce the requisite electro-motive force with very small internal resistance, and at a comparatively low speed.

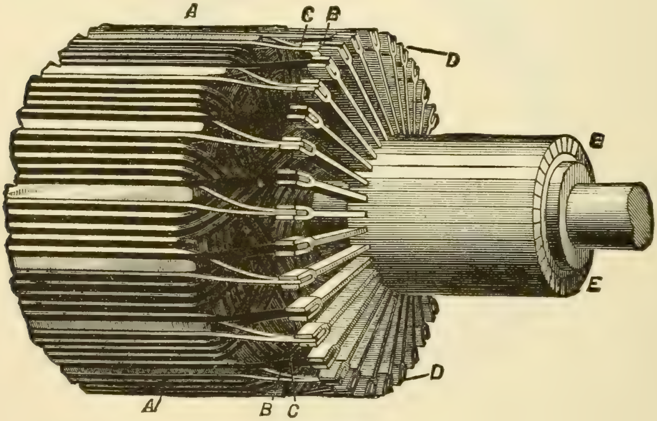


Fig. 452.

The ratio between the resistance of the armature and the normal resistance of the exterior or working circuit, in these machines, is about one to forty, indicating the remarkably small waste of only $2\frac{1}{2}$ per cent. of the total current energy in the armature. The plan of placing the field coils in derived circuit, instead of in the main circuit, has already been referred to. This arrangement of the field, as we have seen, was suggested at an early period in the history of the dynamo machine, but its advantages have not until quite recently been properly appreciated. The field coils are made of comparatively high resistance, so as to divert into the field circuit only a very small fraction of the total current (varying from $2\frac{1}{2}$ to 5 per cent. in the different machines). From the construction of the machine there can be but little mechnical resistance offered by the air, and the friction at the journals is also quite small. The twenty-light arc machine runs at 900 turns per minute, and gives a current of about 18 to 20 ampères with twenty lamps in circuit, having an average resistance of $1\frac{1}{2}$ ohms each, or in all, 30 ohms. The mechanical energy required to effect this work is about 14 horse power. This indicates an extremely high efficiency, probably higher than has been attained in any similar machine.

The Weston machine for supplying incandescent electric lamps is of the same general type, and is equally efficient in its performance. It has been very carefully designed in all its details and is, in one respect at least, entirely unique.

Incandescent lamps are arranged in multiple arc or parallel, instead of in series, and hence it is important that the electro-motive force at the machine should be kept constant, while the quantity or volume of current should vary directly as the number of lamps which are being supplied from the machine.

It is obvious, that with a generator of constant electro-motive force, a system of incandescent lights would be entirely self-regulating; for since $C = \frac{E}{R}$, if E be constant, C will vary inversely as R; but in the multiple arc system of distribution, the resistance varies inversely as the number of lamps in circuit; and accordingly with E constant, C varies directly as the number of lamps, assuming of course that all the lamps are alike in their resistance.

In any dynamo-electric machine, a variation in the external resistance reacts upon the quantity or volume of the current generated, and in addition to this, the electro-motive force of the current is affected by variations in the quantity, so that any considerable increase or decrease in the number of lights in circuit, materially varies the strength of the current passing through the remaining lamps and makes a readjustment of the machine necessary. Regulators of various kinds have been used to overcome this difficulty, which operate to vary the strength of the field to compensate for changes in the number of lamps in circuit. Such devices, whether manual or automatic, are obviously objectionable, as they not only complicate the apparatus, but they cannot be relied upon in all cases to act quickly enough to protect the lamps in case of a sudden increase in the current.

Mr. Weston has succeeded in constructing a machine of which the electro-motive force is constant under all variations in the resistance of the external circuit, and is, therefore, practically independent of the quantity of the current. The most sudden and extreme fluctuations in quantity seem to exert no appreciable influence upon the electro-motive force. It has been found that with the 100 machine, 99 of the lamps may be switched out at once without endangering the remaining lamp or perceptibly affecting its brilliancy. This is a most remarkable result, and its practical importance in connection with the incandescent system of lighting can hardly be overestimated.

In order to accomplish this end a number of changes were made in the form and in the proportion of the different parts of the machine. It was found to be essential to construct it in such a manner that the inductive influence of the field magnets, by which the polarity of the armature core is largely determined, shall so far preponderate over the inductive influence of the currents traversing the coils of the armature, as to practically neutralize the effect of the latter, or at least to cause the polar line of the field and that of the armature to be practically coincident at all times during the normal operation of the machine within the limits of the strength of current which it is designed to maintain. The attainment of this result is materially aided by reducing the internal resistance of the armature coils to the lowest possible point, and eliminating as far as possible all local action therefrom. In fact if it were possible to construct an armature having coils without appreciable resistance, no other modification of the ordinary machine would be necessary. In order to secure the necessary coincidence between the polar lines of the field magnet and the armature in the most economical and efficient manner, Mr. Weston makes use of massive and powerfully excited field magnets, provided with the improved pole pieces of contrary magnetic polarity enclosing between them a cylindrical armature of the general construction, which has already been described. The diameter of this armature is such as to nearly fill the cylindrical space between the poles, which latter are brought considerably nearer together than in the ordinary form of machine. By reason of this peculiar construction the magnetic circuit between the pole pieces is practically closed, and the lines of magnetic force are but slightly deflected as they pass through the armature from one pole of the field magnet to the other. The sectional construction of the armature core, which is composed of a series of detached disks as already explained, prevents the circulation within it of Foucault currents, which would otherwise tend to disturb the proper position of the polar line. The armature is wound with conductors of unusually large cross section, and these are disposed about it in the smallest possible number of convolutions, this being important, not only to reduce to a minimum the magnetizing influence of the armature coils upon the core in proportion to the exterior inductive influence of the field magnet, but to reduce the resistance of the armature conductor itself to the lowest possible point. The principle of this machine will, perhaps, be more readily understood by a consideration of the magnetic condition of the core of an ordinary cylindrical or annular armature, having its coils wound in a direction parallel to its axis of rotation. In this case the position of the polar line, that is to say, of a straight line passing through the axis of the armature and through the opposite points of maximum magnetic attraction in the armature core during the normal operation of the machine, is determined by two forces; first, the currents traversing the coils of the armature and the corresponding currents circulating within the body of the armature itself, both of which conspire to establish the polar line at right angles to the polar line of the field, and second, the polarity due to the inductive magnetic influence of the field, which tends to establish a polar line in the armature coincident with its own. These forces acting in a direction perpendicular to each other tend to fix the resultant polar line of the armature in a direction between the two normal directions indicated, the actual angular position depending upon the relative strength of the two forces. That this is true will be obvious upon consideration of the fact that in all prior dynamo machines the diametrical line upon which the collectors touch the commutator, when adjusted to receive the maximum strength of current, is always more or less in advance of the line joining the theoretical maximum points, which is a line at right angles to the polar line of the field. It will be found that in all cases they are more or less advanced in proportion to the strength of current induced in the armature, as compared with the consequent magnetizing influence exerted thereby in a direction at right angles to the action of the field magnet. No doubt the irregular rise and fall of the electromotive force, observable in many dynamo machines, arises largely from this angular displacement of the polarity of the armature, the effect of which is to reduce the number of lines of force cut by the coils in the same manner as by the removal of the field magnets to a greater distance from the armature. Mr. Weston discovered that by properly observing the conditions above indicated in the construction of his machine it was possible to bring the polar line of the armature into close coincidence with the polar line of the field, and thus to make the actual points of maximum potential upon the commutator correspond with the theoretical points, rendering it possible to vary the external resistance to any extent within the working limits of the machine, without perceptibly changing the electro-motive force or potential, as measured at the terminal of the armature circuit. Such a machine may be run in either direction without altering the position of the brushes, and so long as the speed of the rotation of the armature is kept constant there will be no perceptible variation in potential.

The armature of this machine is wound in a peculiar manner, so as to bring an even number of convolutions into each single layer, each convolution being connected with a separate commutator section. This is done by winding side by side a portion of the convolutions in pairs and another portion singly, beginning alternately from opposite sides of the same end of the cylinder and afterwards uniting the convolutions in such a manner as to form a single circuit.

DE ROMILLY'S MACHINE.

The De Romilly generator, which has been mentioned in connection with Mr. Weston's early investigations, was patented in France, in 1866. This invention, which embodies some of the most valuable discoveries in the science of dynamo-electricity, is described in the patents as follows:

When we cause a metallic plate to pass before the pole of a magnet, perpendicularly to the axis of this magnet, whether the movement is reciprocal, or whether, having the form of a disk, it revolves without interruption before the poles, there are set up in this place induced currents perpendicular to the direction of movement, and of the same sign, before and after the passage in front of the pole. This phenomenon, which was discovered by Arago, has received the name of magnetism of rotation, or magnetism of movement. It is the collection and utilization of induced currents, which are produced when a metal plate passes before the pole of a magnet, perpendicular to its axis—currents which are set up perpendicular to the direction of the passage of the current—that is to say, the collection and utilization of those currents due to what is named magnetism by movement, or magnetism of rotation, which I propose to reserve by the present patent. Induced currents, which up to the present time have been utilized by employing artificial or natural magnets, have always been produced by the successive reciprocations of a bar of soft iron carrying one or several wires coiled in a direction perpendicular to its axis, and passed in front of the inductor magnet in such a way as to be magnetized or demagnetized rapidly (as in the Clarke and Alliance machines), or they have been produced by the passage, and the successive and rapid interruptions of a current from a voltaic battery, in an inductor wire, coiled round a bar of soft iron, and itself covered with a coil, in which is set up the induced current (as in induction coils or Rumkhorff machines). Here it is necessary to pass before the pole of a magnet, or between the two poles of a magnet, a piece of metal of high conductivity—a plate or a copper wire, for example—and to collect the current thus obtained. Experiments made up to the present time have been conducted with revolving disks, or with plates passing and repassing before the poles. The currents thus produced are very weak, which has rendered it impossible to collect them so as to employ them as ordinary induced currents. What renders the current so feeble is, in the first place, the continuity of the plate or disk, which allows it to be dispersed with extreme facility, so that only a small part can be taken off to demonstrate its existence.

To obviate this inconvenience, it would suffice to pass before the pole a succession of wires, separated from each other, and each extremity of which would communicate with a fixed conductor that would come in contact successively at the moment of their passage before the pole. The current would thus be produced successively on the passage of each separate wire before the inductor pole, without any part being lost, as is the case with a continuous plate. This current, very feeble when the wire passes before a single pole, is greatly increased when it passes between two opposite poles.

I now assume that it is possible to connect each of these separate wires to the adjacent wire, in such a way that the current obtained in one may be in the same direction, and, as it were, a continuation of that which is obtained in the other; in this manner a kind of battery would be obtained, each wire of which would represent an element. To arrive at this, we cause to revolve between two poles of the same name—both north or both south—a plate of soft iron covered with well insulated wire, and coiled in such a manner that the flattened spirals in this iron core are presented perpendicularly to an imaginary line joining the two poles, and perpendicular also to the line indicating the direction of movement of the plate. The soft iron will thus assume a polarity contrary to that of two similar poles. The passage of the plate covered with wire will give rise, on the one side, to a current procured by the wire travelling before a north pole, for example, and a south pole is produced in the plate itself by the influence of the fixed pole, while on the opposite side of the plate there is set up in the coil of wire a contrary current produced by the passage in the same direction before a south pole, resulting from the influence on the soft iron plate, and the other fixed north pole. The semi-spirals on one face of the plate partake of the same movement as the semi-spirals of the other face, in a contrary position, referred to a fixed pole, and the pole produced by induction.

This is precisely what is required in order that the currents which have to flow around the core may form at each semi-coil, at each coil, and throughout the series of coils, a continuation of each other. If, then, we suppose a long plate of soft iron thus surrounded, and passing between two similar poles on the two extremities of the coil, being connected by a conductor to a galvanometer, this latter will indicate the presence of a continuous current as long as the plate moves in the same direction, but which will be interrupted when the movement is arrested, and which will take the contrary sign when the plate travels in the opposite direction. The sign of the current can also be changed by the introversion of the poles, by the direction of the movement, and also by the direction of winding the coils to the right or left. Further, this wire coiled singly, can be covered by a second wire wound parallel to it, and brought back over itself, so as to surround the soft iron core several times. Each thickness of the coil superposed will add its current to that of the preceding coil. In this manner, instead of a feeble current, we shall have one, the energy of which will depend on the power of the magnets, on their proximity, on the purity of the soft iron core, on the number of superposed coils, and upon the velocity of movement.

Now to consider an arrangement which will make this process practical, and by which one can collect the induction currents of which we have been speaking. Instead of a soft iron plate, we will take a plate curved in such a way as to form a cylinder, of which the diameter is much greater than the height. We will connect this cylinder by radial arms converging from one side to a rigid shaft passing through the centre of the cylinder; this shaft will rest in bearings in which it may revolve rapidly. The cylinder, entirely open within, has thus only one of its sides partially occupied by the radial arms, that serve to fix it to the central shaft. This arrangement allows of winding longitudinally on the cylinder, a copper wire covered with an insulating material. We will first assume only half the circumference of the cylinder to be thus covered, then we will place in close proximity to one side of the cylinder, two magnets, each formed of a bar of steel magnetized; the similar poles of these two magnets—the north, for example—are opposite to one another, and allow the iron cylinder, one half of which is surrounded with insulated wire, to pass between them; in this way the wire receives an opposite polarity. We will now do the same thing with the side of the cylinder diametrically opposite, in such a way that on this, as on the other, a magnet passes within the cylinder (and parallel to it), having its south pole in close proximity, while a second similarly magnetized bar is placed outside, in such a way that the cylinder passes between two south poles. Now we will connect each end of the wire coiled on the half circumference to two terminals placed near the shaft, and insulated from each other; and we will connect, by a conductor, these two terminals with a galvanometer. Then, by means of a pulley, fast on the shaft of the apparatus, we will impart a movement of rotation to the cylinder. The coil successively revolves perpendicularly between the two poles, north on one side, and south on the other. The soft iron core will assume a polarity contrary to that of the magnets, in the portion comprised between the poles, and subjected to their influence. From this there results, as in the plate to which reference has been made, similar currents, as long as the half-circumference on which the wire is coiled passes between two poles of the same name; but so soon as it passes between magnets of the opposite polarity, the current will change its sign. Thus one half turn will give a current of one sign and the complementary half turn will give a current of the opposite sign. If we continue the coiling around the cylinder in the same direction—to the right, for example—in such a way as to surround the whole cylinder, we shall not perceive any current, since, whilst half the circumference passed before one pole, the other half circumference would pass before the opposite pole, giving a current the inverse of the former. To avoid this, it is necessary to utilize the effect of the two poles, which is easily done by coiling the wire of one half circumference in a direction contrary to that of the other half. Thus, if the former be coiled to the right, the latter must be coiled to the left; in this manner the effects of the pole being reversed with each half revolution, at the moment when the half circumference to the right passes between the north poles, the other half, coiled to the left, passes between the south poles, and they will give simultaneously a current of the same sign, the opposite directions of winding serving to destroy the opposition of the poles. The first half circumference having passed before the north poles, will present itself before the south poles, passing between them, while the second half circumference passes before the north poles. The current in the first half circumference will change its sign in passing before the south poles, at the same time that a similar change will be effected for the second half circumference before the north poles. At each half revolution, the current in the two semi-circumferences with the wire coiled in opposite directions will change its signs simultaneously. Thus for each revolution there will be two opposite currents which will follow one after the other through the whole of the wire coiled around the soft iron core. If, instead of simple insulated terminals we place a commutator on the shaft of the cylinder, we shall perceive currents always in the same direction, and which will produce the effect of continuous currents.

In place of a single coil of wires, several thicknesses of wire may be superposed, and instead of a pair of magnets on each side we may place several pairs in such a way as to surround a half circumference inside and outside with similar poles, and the whole of the other half circumference within and without poles

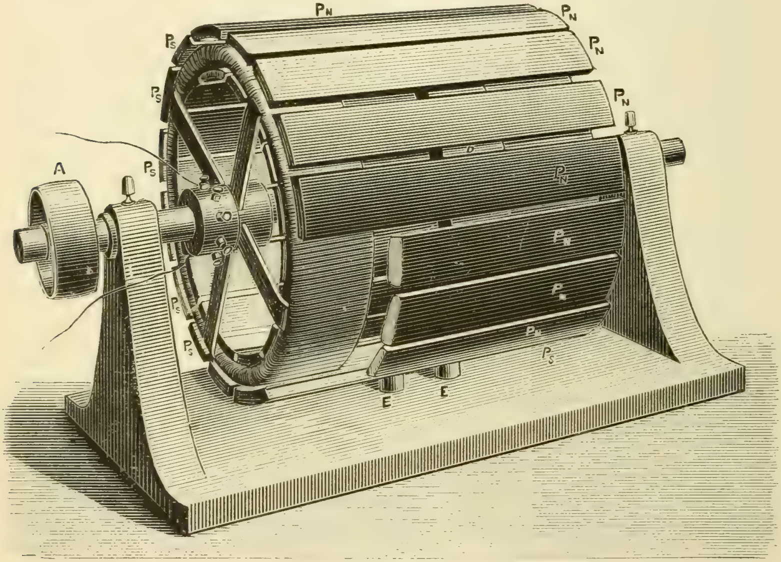


Fig. 453.

of an opposite sign, as shown in figs. 453 and 454. A, driving pulley; D, copper ring, connecting circles of magnets, PN, PS. Collectively these series of magnets form two concentric cylinders between one end of which the soft iron ring covered with its coils revolves. The electro motive force of the current increases with the number and length of coils, with the speed of rotation, and the number and power of the magnets. Each complete turn or half turn of wire is attached by the two ends, to a brass terminal placed on a wooden bar, and fastened to the radial arms of the cylinder. With these terminals we connect the various superposed wires, either in such a way as to form only one large cable, or end to end, so as to be able to vary at will the electro motive force of the apparatus.

But it must be clearly understood that such an apparatus is only one of a thousand possible arrangements that may be indefinitely varied, and by which the principle protected by this patent may be put in practice. For example, the soft iron ring may be given the form of a torus flattened perpendicularly to the axis of rotation, and having its wire coiled radially, so as to form a sort of disk pierced with a large central hole, in order to allow the radial coilings of the wire, the ring being mounted rigidly on a shaft passing through its axis. Magnets would be placed radially around the disk on each side, with similar poles opposite each other, as in fig. 455. A, driving shaft; B, commutator; T, flattened ring; PN, PS, north and south poles of magnets. Or the soft iron core may be formed as a cyl-

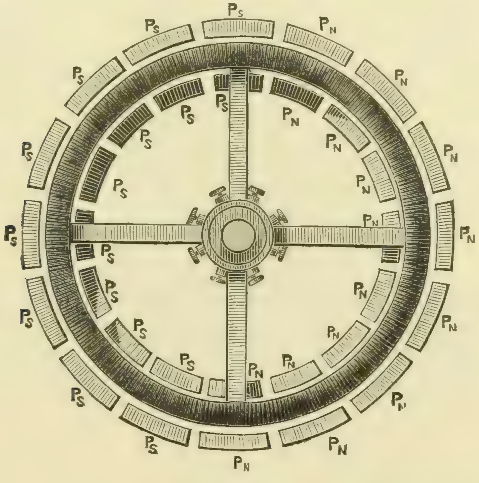


Fig. 454.

inder with flat parallel ends, having a steel shaft running through its axis, and fixed to it by means of radial arms or by blocks of wood driven into the cylinder at intervals. This shaft rests in bearings, and a pulley is arranged to drive it. I surround this cylinder parallel to its axis with an insulated copper wire, following always the same direction and passing from one side to the other by a turn diametrically across the ends of the cylinder. On the first coil thus made I superpose, always

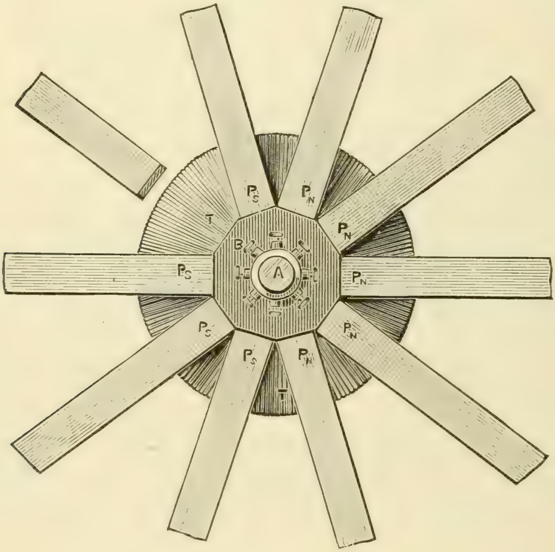


Fig. 455.

winding in the same direction, a second turn, and in this way several coils in succession, and I join the ends of the wire thus wound to a galvanometer. Diametrically on each side of the cylinder I place magnets, each having their opposite poles turned toward the cylinder. The magnet on one side turns its north pole, whilst opposite, the magnet on the other side turns its south pole to the cylinder. These magnets may each of them extend over one half the surface of the cylinder. If now we cause this cylinder to revolve, we shall set up, at each half turn, a current of an opposite direction, but simultaneously of the same sign in the coils. An analysis of the manner in which each element of the wire is presented to the poles is too similar to the preceding explanation to require repetition. A commutator placed on the axis of the apparatus allows the currents to be collected so as to be practically continuous. Each turn and each half turn on the cylinder can be made by a separate wire, the two ends of which, each going to a terminal, can be joined to the other wires in such a way as to give to the current the required electro motive force. Practically the envelopment of the cylinder cannot be affected by wires placed one after the other, and coming in succession across the diameter of the two bases. It is necessary that they should clear the shaft, and then, superposed on each other, they would form around the shaft a thickness equal to the sum of the collective thickness of wire in all the coils. This thickness would be doubled with the second coil of wire, tripled with the third, and so on. To avoid this inconvenience, I divide the circular bases of the cylinder into six or eight equal parts, and I wind the wires in such a way as to form in each division a parallel band like a ribbon, along each side of the cylinder, and passing diametrically across the ends. These bands would be necessarily opened in the middle to make room for the shaft, and then brought together again. Each band of parallel wires is laid close to the succeeding one upon the cylinder, and they are superposed on each other in passing across the ends, so that the entire surface of the cylinder will thus be covered, as shown in fig. 456. In this way we shall have at each end a height of superposed wires which will only be the sum of the thickness of one wire multiplied by the number of superposed bands.

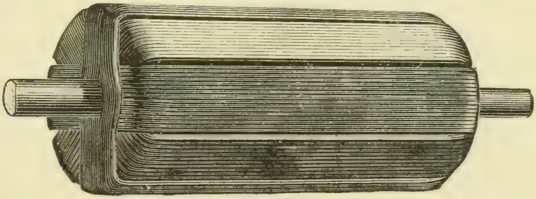


Fig. 456.

CHAPTER VIII.

THE ELECTRICAL TRANSMISSION OF POWER.

Electricity is the youngest form of energy with which we are acquainted—its evolution as a practical motive power having been consummated within the past ten years—but notwithstanding its recent development, it occupies at the present time a position of no inconsiderable importance as an actual working force.

Although the only available source of electric energy was, until lately, the galvanic battery, attempts were made from the days of Volta, at the beginning of the present century, to employ it for obtaining and transmitting power; and though the cost of procuring power from the consumption of zinc is so much greater than from coal that it must necessarily have rendered the production of power from this source altogether too expensive for practical use, still the efforts which were made in this direction were useful and necessary, and largely contributed toward the accumulation of that fund of knowledge of electro dynamics which has at last enabled us to obtain and transmit energy in an exceedingly practical and economical manner. We therefore feel justified in briefly describing these early efforts for converting voltaic electricity into motive power by means of electro dynamic motors operated by galvanic batteries.

ELECTRO DYNAMIC MOTORS.

Electro-dynamic motors are machines which do mechanical work at the expense of electric energy. The motive power is an electro magnetic force—a force susceptible of being destroyed instantaneously by a physical and non-mechanical cause. As a jet of cold water brings about condensation of the steam, whose elastic force raises the piston in the cylinder of a steam engine, so every electro magnetic machine loses its properties the moment that the electrical current ceases to circulate in it. It was known at a very early period that a magnet would attract the opposite pole of another magnet, and that every magnet placed in a magnetic field tends to turn around and set itself along the lines of force. Very soon after the invention of the electro magnet, which gave us for the first time a magnet whose power was under control, it was perceived that an electro dynamic machine could be constructed in which an electro magnet, placed in a magnetic field, should be pulled round, and that the rotation should be kept up continuously by reversing the current at appropriate intervals.

BARLOW'S ELECTRO MOTOR.

As early as 1826 Barlow caused a disk of copper to rotate between the poles of a magnet by sending a current at the same time perpendicularly through the disk from the axis to the circumference, where it passed into a cup of mercury arranged to make electric contact with as little friction as possible. Fig. 457 represents the Barlow motor.

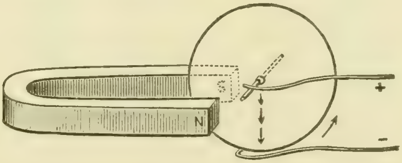


Fig. 457.

DAL NEGRO'S ELECTRO MOTOR.

In 1830 the Abbé Salvatore dal Negro, Professor of Natural Philosophy at the University of Padua, invented an electro dynamic motor in which a permanent magnet was made to oscillate between the two poles of an electro magnet which changed polarity at each oscillation ; and this oscillating movement was easily transformed into a continuous movement of rotation. Fig.

458 represents the first type of the Dal Negro motor. A is a permanent magnet, movable around an axis situated at about one third of its length, and the upper extremity of which is cap-

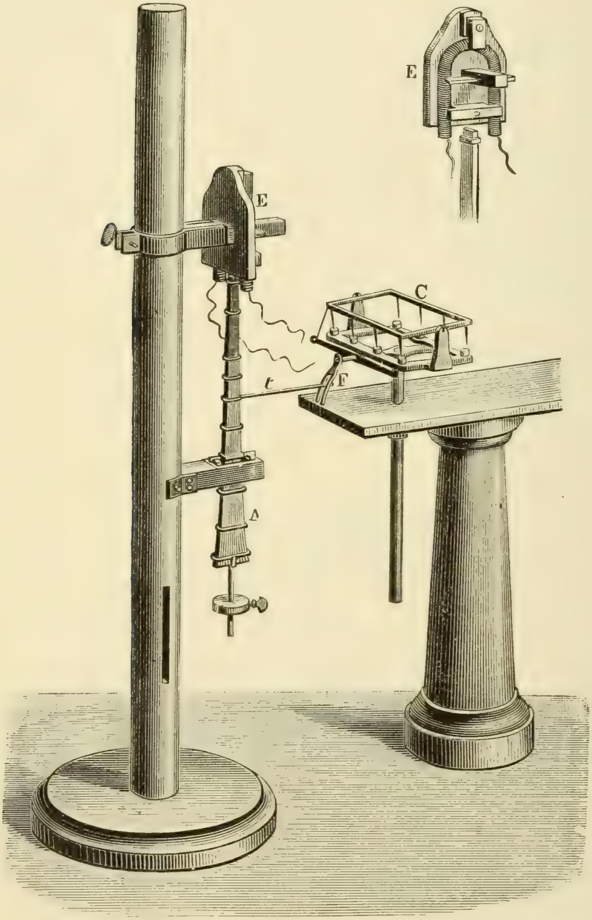


Fig. 458.

able of oscillating between the two branches of an electro magnet, E, represented separately in the figure. A current, on being sent into the electro magnet, passes through an eight cupped mercurial

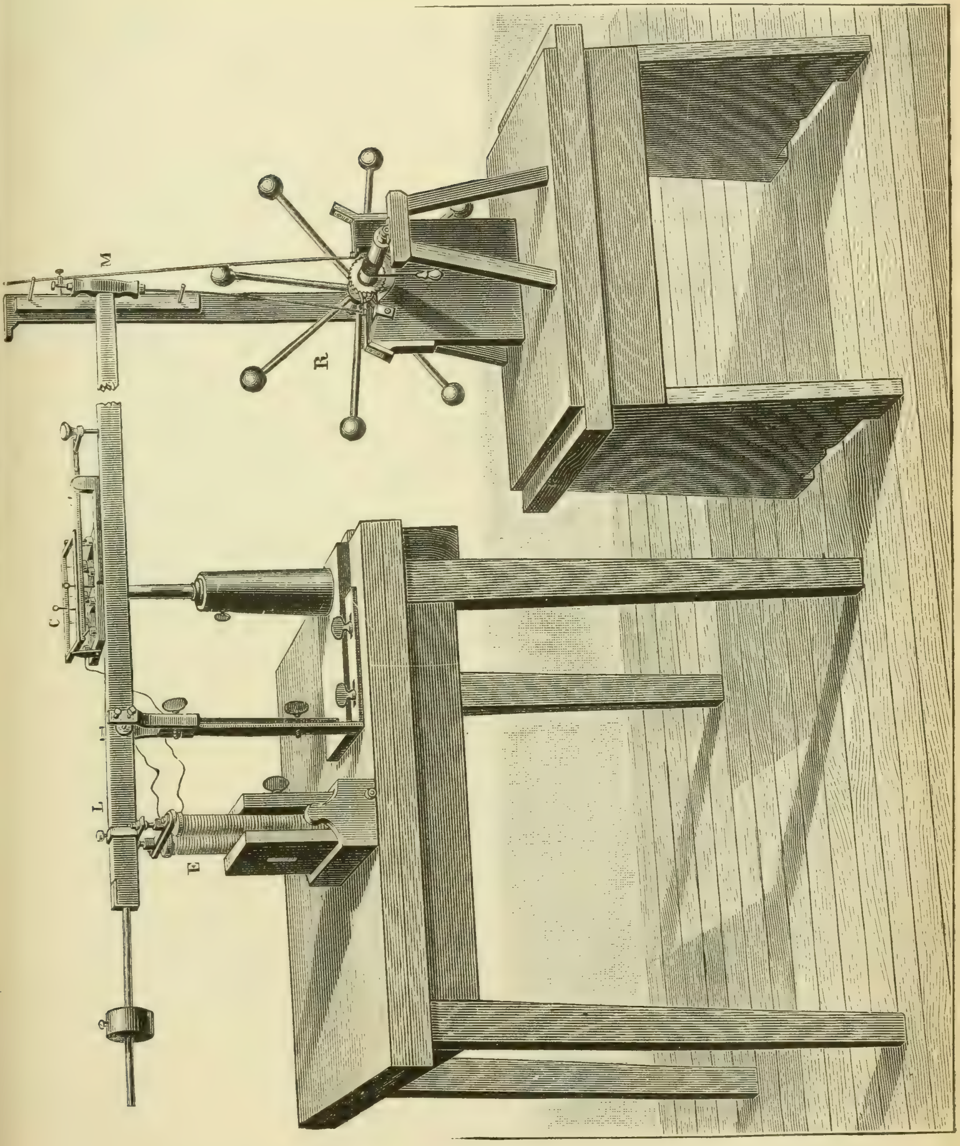


Fig. 459.

commutator, C, controlled by the oscillating magnet by means of a rod, *t*, and a fork, F. As a result of this arrangement, when the permanent magnet has been attracted toward one of the poles of the electro magnet this very motion of attraction, acting upon the commutator, changes the direction of the current, and the permanent magnet is repelled toward the other branch of the electro magnet, and so on. The movable magnet, when it touched the poles of the electro, abutted, not against the iron itself, but against the insulated wire that covered it. The author thus avoided those inconveniences connected with remanent magnetism which later on were to embarrass other inventors when polarized armatures were applied to electric telegraphs. The second type, which was constructed in 1831, is shown in fig. 459.

In this arrangement there is the same play of the commutator as in the former, but it is this time controlled by a horizontal lever, L, which, instead of itself constituting the armature, supports the latter above the electro magnet, E. The lever, L, terminates in a sort of hammer, M, which is prolonged beneath by a stiff rod that controls a click. This latter acts upon a ratchet wheel, and thus sets in motion a sort of wheel, R, composed of rods terminating in balls. In this case the motor, instead of keeping up its motion, produced a small amount of work.

Following Dal Negro, a great many electro motors were devised, either operating in a similar manner or by the seesaw motion of soft iron armatures, attracted by electro magnets, and then falling back by their own weight. But Jacobi, as early as 1834, showed by experiment that every arrangement by which the attractive or repulsive power of the electro magnet produces an oscillating movement is contrary to the mode of action of electro magnetism, and that every useful electro motor in which the utilized force is derived from an electro magnet must have a continuous circular primitive movement.

JACOBI'S ELECTRO MOTOR.

Fig. 460 represents Jacobi's machine. Four horseshoe electro magnets are arranged horizontally against a vertical disk, S, movable around an axis, A A, opposite to four others, placed upon a fixed frame, T, in such a manner that the poles of the former may come exactly opposite to and at the smallest possible distance from the poles of the fixed electro magnets. The same current passes simultaneously in all the coils, and always maintains the same direction in the system of fixed electro magnets, but

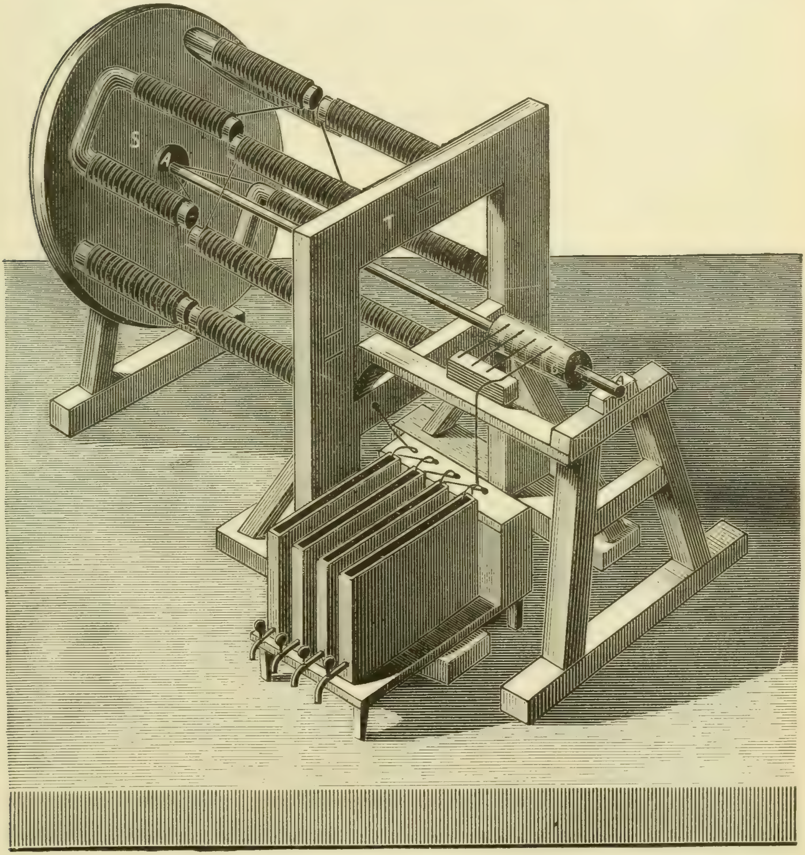


Fig. 460.

is able to change in direction in the system of movable electro magnets.

The current from a powerful battery was passed through commutator C, by which it was sent through all the coils of the electro magnets. This tended to make them magnetic, and as they attracted each other the disk rotated. By means of a commutator carried on the shaft, the current was made to reverse eight times per revolution, just as the poles of the two sets of magnets arrived opposite each other. The result was that the attraction between the poles ceased and repulsion took place, which further assisted the motion. As the poles were alternately of different polarity, the reversal also had the effect of causing attraction between each pole of one set and the next of the other.

Jacobi subsequently modified this motor so as to increase its power. In the new form two sets of electro magnets were fixed to stationary frames, one on each side of the rotating disk, and each set was composed of twelve electro magnets. The electro magnets on the rotating disk were made in the form of bars passing entirely through the disk. With this motor, which was constructed on a large scale, experiments were made, with a view to the determination of its applicability to navigation. The motor was used to propel a boat on the river Neva. This boat was 28 feet long, 7 feet wide, and carried 14 persons. In the first experiments, made in 1838, the battery power was furnished by 320 Daniell cells. In later experiments, made in the following year, the battery power was furnished by 138 Grove cells, and the fumes and gases are said to have been evolved so abundantly that a stack had to be provided for their escape. The highest speed attained was less than three miles per hour. These experiments were made at the desire of the Emperor Nicholas, and it cost him $12,000 to find out that this method of employing electrical energy was not economical or practical.

DAVENPORT'S ELECTRO MOTOR.

In 1835 Davenport, of New York, constructed an electro motor in which the action of electro magnets upon permanent magnets was employed. In this machine two small horizontal electro magnets, placed across, and movable around a vertical axis, revolve in the interior of a circle also horizontal, formed by two permanent magnets, bent into semicircles, and whose poles of contrary names face each other. The extremities of the electro magnets, which change polarity by means of a commutator, are attracted and then repelled by the poles of the permanent magnets.

FROMENT'S ELECTRO MOTOR.

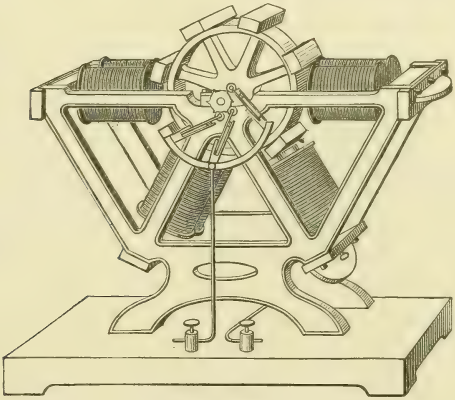


Fig. 461.

Froment's machine, which is represented in fig. 461, is founded upon the attraction that is exercised by an electro magnet upon an armature of soft iron. It is composed of four fixed electro magnets, supported by a cast iron frame, in which the same current circulates by turns. Eight soft iron armatures are arranged upon a movable wheel; when an armature arrives near to the pole of an electro magnet, the latter is magnetized; then this magnetization ceases at the moment when the attracted piece of soft iron is situated opposite to it, and the wheel thus receives a series of impulses, which bring about a rapid movement. The distribution of the current is as follows:

Upon a semicircle of copper, around the axis of the apparatus, are arranged three rolling commutators, each of which is composed of two metal plates, between which there is electric communication only when the lower plate is raised. If, therefore, the upper plate communicates always with one pole of the battery, and the lower plate with the wire of an electro-magnet, which, by its other extremity, is connected with the other pole of the battery, the current will pass through the helix as soon as the lower plate is raised, and will cease passing as soon as it falls back. The teeth of a small wheel, fixed upon the axis of the machine, raise in turn the wheels of the commutators, two of which correspond to the two extreme electro-magnets, while the third is in connection with the two lower electro-magnets, which are always found in the same condition. Magnetization takes place only when the armature is very near the poles, and does not last long, since the free electro magnets are successively magnetized in the interval of time that elapses between the passing of two successive armatures before the same pole. When an electro motor is in action, an extra current is produced every time the current is interrupted or reversed, and a spark is produced at the place of interruption which oxidizes the contacts of the commutators, and rapidly brings about irregularities in its action. Froment succeeded in diminishing the spark due to the extra current by so arranging the commutators•that the current begins to pass into the neighboring conductor before it ceases in the circuit in which it is travelling.

A great number of electro motors have been constructed, differing from Froment's only by modifications of little importance, in all of which the armatures pass before the electro magnets in a line perpendicular to their axes, and remain consequently always at a greater or less distance from their poles; but as the attractive power of an electro magnet increases rapidly as the distance diminishes, all the force which the electro magnets are capable of developing is not thus utilized. It was, therefore, desirable to devise an arrangement whereby the electro magnets and armature might come into contact, while, at the same time, the shock and inconveniences of the oscillating apparatus were avoided. With this end in view, Wheatstone, Froment and Marié devised electro motors, in which a wheel, furnished at its circumference with armatures or with electro magnets, rolls against the interior surface of a circle, tangent to the poles of electro magnets, fixed symmetrically all around. The movable wheel imparts a movement of rotation to the axis of the machine, which passes through the centre of the fixed circle, and advantage is thus taken of the magnetic action up to the point of contact of the magnetic masses.

LARMANJEAT'S ELECTRO MOTOR.

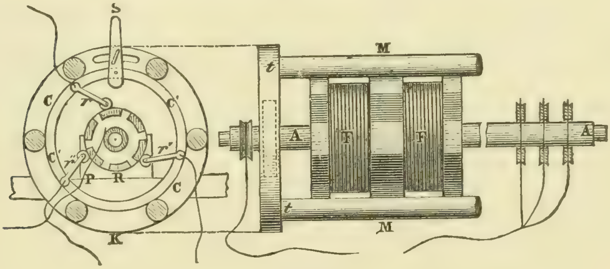


Fig. 462.

Larmanjeat obtained better results by a different arrangement. Fig. 462 represents this apparatus. The armatures are cylinders of soft iron, M, able to turn around their axes, which are fixed, and are placed parallel to each other, so as to form a cylinder, about a yard in length, the transverse section of which is represented by the left hand part of fig. 462. Three electro magnets, arranged one after the other, are movable around their common axis A, which is also the axis of the cylindrical figure, formed by the armatures. The right hand part of the same figure represents one of these electro magnets, which is composed of a bar of soft iron, furnished with three disks perpendicular to its axis, and separated by two helices, F F, which thus constitute a double circular electro magnet; these iron disks are tangent to the cylinders of soft iron, which, by their mobility around their respective axes, oppose no obstacle to their movement of rotation, even when in contact with them, and their circumferences present six sectors in copper, equally distributed; when an iron sector arrives near an armature, the current passes in the helices, and an attraction is produced which lasts till the iron part of the circumference of the disk is situated symmetrically on either side of the contact point, when the magnetization ceases, then recommences for another sector of iron, and so on. The lines of separation of the copper and iron sectors upon the three electro magnets form a helix, which causes each armature to be continually in action upon one of its points. The commutator which is shown in K at the left of the figure is composed of a movable part with its axis, that is the wheel R, and of a fixed part, the circles C C and C′ C′. The wheel R is composed of six metallic parts. The circle C′ C′, concentric with C C which carries the armatures, supports the rollers r r' r'', which press continually upon the wheel R during its rotation. The rollers r r' r'' are each in connection with one of the circular electro magnets, and the current is conducted to the conducting plates of the wheel R by a rubber, P. In order to regulate the position of the rollers r r' r'', in accord with the conducting parts of the wheel R, a small lever has been adopted to the circle C′ C, and this lever carries a movable screw in a groove made in the circle C C, allowing the system of the three rollers to move backward and forward to a certain extent, and also of displacing it sufficiently to completely reverse the direction of rotation of the machine.

ROUX'S ELECTRO MOTOR.

The Roux motor has only two electro magnets, but these two are of very great size. Fig. 463 represents a portion of this machine suspended by two articulating shafts, A B, C D, two large soft iron plates, E F, to which are fixed two long levers connected with a double crank, G G′, adapted to the same vertical axis, H I. It is upon this axis that the commutator and fly wheel is situated. When the motor is inactive, one of the plates is found lifted about an inch above the corresponding electro magnet, during which the other plate is completely thrown down. As soon as the current passes in the apparatus, the raised plate is found attracted; but the shafts which support it describing during this passage an arc of a circle, this plate is found, accomplishing wholly its movement below, forced aside. Now, it is this component of the attractive force which is utilized to act upon the crank of the motor arbor. When the mechanical function of this iron plate is terminated, the current is found conducted into the second electro magnet, which just before has been inert, and this, operating in the same manner as the first, continues the movement.

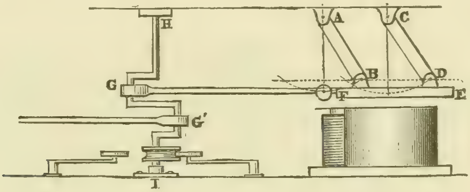


Fig. 463.

PAGE'S ELECTRO MOTOR.

Fig. 464 represents Page's electro motor. It is composed of two solenoids, *a a′*, fixed horizontally in such a manner that their axes are in the prolongation of each other; two cylinders of soft iron, *b b*, joined by a copper rod, are connected to a system of slides, F F, which allows them to oscillate parallel to the axis of the solenoids, and which is articulated to a crank, by means of which the backward and forward movement is transformed into a circular movement. The current passes alternately through each coil by an eccentric disk on the axis, which touches first one and then the other of two springs, *e e*, connected by wires with the solenoids. A large motor of this description was constructed by Page in 1850, which developed over ten horse power. Page sought to apply his motor to locomotives, and it is said that he actually constructed an electric locomotive to demonstrate the practicality of his scheme. But he never achieved much success, as might have been foreseen. Among the improvements which Page introduced was that of making each solenoid double, so that the arms of a U magnet could slip into them instead of one single bar.

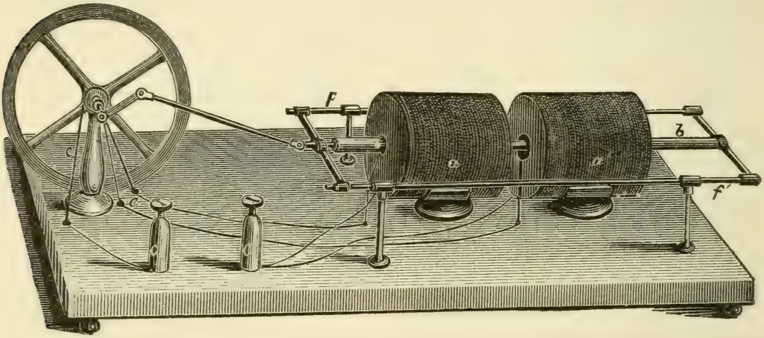


Fig. 464.

Du Moncel also devised an analogous apparatus, in which the helicas themselves were able to oscillate, as do the cylinders of oscillating steam engines, by which the rod is articulated—that is, connected with the soft iron, directly with the crank of a wheel.

BOURBOUZE'S ELECTRO MOTOR.

Page's suggestion was further developed by Bourbouze, who constructed the curious motor depicted in fig. 465, which looks uncommonly like the ordinary walking beam steam engine. We have here a beam, crank, fly-wheel, connecting rod, and even an eccentric valve gear and a slide valve. But, for cylinders, we have four hollow electro-magnets, E E, E′ E′; for pistons, we have iron cores, that are alternately sucked in and repelled out; and, for slide valve, we have a commutator, which, by dragging platinum-tipped springs, *a b c*, over a flat surface made of three pieces of brass, separated by two insulating strips of ivory, reverses at every stroke the direction of the currents in the coils of the electro magnets. This machine, while very ingenious, is, in point of efficiency, far behind many other electric motors.

ELIAS ELECTRO MOTOR.

Fig. 466 represents in section and fig. 467 in perspective the electro motor of Elias, of Amsterdam, constructed in 1842. In this machine there is an exterior iron ring, about 14 inches in diameter and 1½ inches wide, divided into six equal sections by six small blocks which project from the inner face of the ring, and which act as so many magnetic poles. On each of the sections between the blocks is rolled a coil, of one thickness only, of copper wire of No. 18 B W G, enclosed in an insulating casing of gutta-percha, giving to the conductor thus protected a total thickness of $\frac{1}{5}$ of an inch. The wire forms 29 turns in each section, and the direction of the winding changes at each passage in front of a pole piece. The ends of the wire coinciding with the horizontal diameter of the ring are stripped of the gutta-percha, and are connected to copper wires which are twisted together and around two copper rods, which are placed

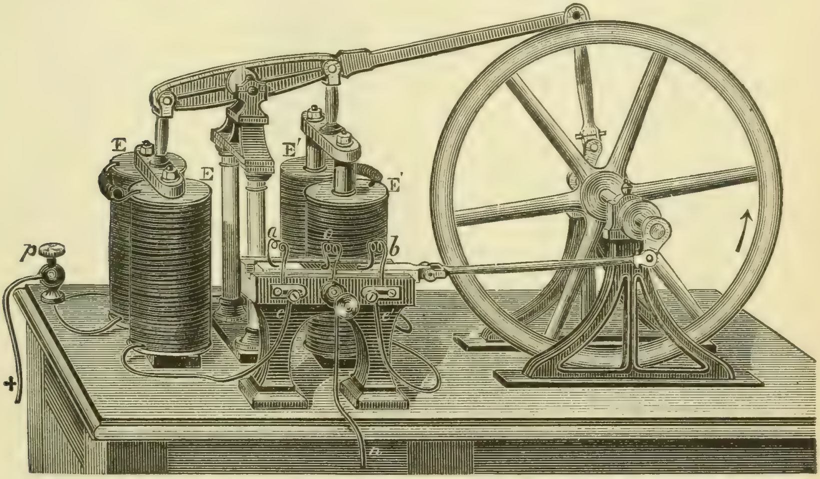


Fig. 465.

vertically, their lower ends entering two small cavities made in the base of the apparatus. The circuit is thus continuous with two ends at opposite points of the same diameter. The ring is about $1\frac{1}{10}$ inches thick, and is fixed to two wooden columns by two blocks of copper. If a battery be connected by means of the copper rod, the current, by magnetizing the outer ring, will create six consecutive poles on the various projecting blocks. The inner ring, E, is about 11 inches in outside diameter, and

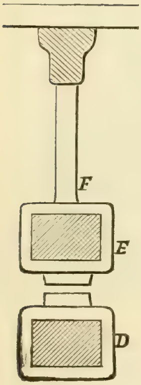


Fig. 466.

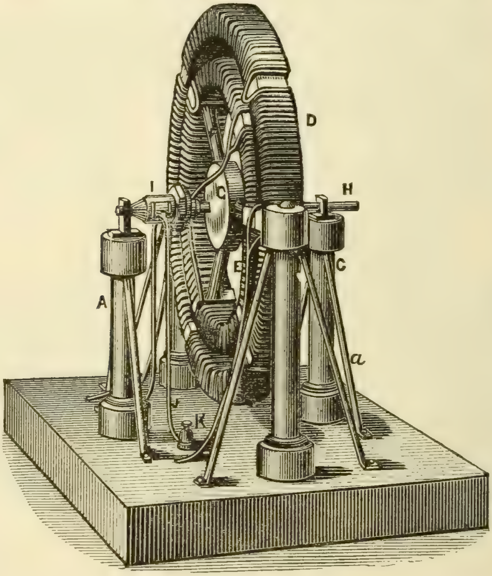


Fig. 467.

is also provided with a series of six projecting pieces, which, in their rotation, pass in succession very close to the projecting pole pieces of the outer ring. In the intermediate spaces the distance between the coils of the inner and outer ring is half an inch. The inner ring is movable, and is supported by three wooden arms, F, fixed to a boss, G, which is traversed by a spindle, supported in bearings by the columns A and C. A coil is wound around this ring in exactly the same way as that on the outer ring, the wire being of the same size, and the insulation of the same thickness. The insulating material is also stripped from the ends of the wire at points of the diameter opposite each other, and the six sections form a continuous circuit. At the two points of junction they are connected with a hexagonal commutator placed on the central spindle ; one end corresponding to the sides 1, 3 and 5, and the other to the sides 2, 4 and 6. Two copper rods, J, fixed on the base to two plates of copper, furnished with binding screws, are widened and flattened at their upper ends to rest against opposite parallel sides of the hexagon. If the battery is put in the circuit the current in the inner ring will produce six consecutive poles, the names of which will change as the commutator plates come into contact successively with the sides of the hexagon. Consequently, if at first the pole pieces opposite each other are magnetized with the same polarity, a repulsion between them will be set up which will set the inner ring in motion, and the effect will be increased on account of the attraction of the next pole of the outer ring. At the moment when the pole piece thus attracted comes into the field of the pole of opposite polarity, the action of the commutator will change its magnetization, whilst that of the pole pieces on the fixed ring always remains the same; the same phenomenon of repulsion will be produced, and the inner ring will continue its movement in the same direction, and so on. To the attractive and repulsive action of the magnetic poles has to be added the reciprocal action of the coils around the two rings, the action of which is similar.

THE MODERN ELECTRO MOTOR.

All the electro motors which have thus far been described depended for their source of energy upon the galvanic battery, the only available source previous to the invention of the dynamo-electric generator. A very little consideration will show that their economical working was hopeless. A voltaic battery, wherein electric currents are generated by dissolving zinc in sulphuric acid, is a very expensive source of power. To say nothing of the cost of the acid, the zinc—the very fuel of the battery—costs more than forty times as much as coal, and is a far worse fuel; for while an ounce of zinc will evolve heat to an amount equivalent to 113,000 foot pounds of work, an ounce of coal will furnish the equivalent of 695,000 foot pounds. Thus zinc gives in burning only one sixth of the effect in energy that coal does; and taking the difference in the cost of zinc and coal, it will be seen that the cost of energy, in the case of a galvanic battery, is, roughly speaking, 240 times greater than in a steam boiler. Thus handicapped, it was impossible to make electro motors available for producing powerful effects, and therefore all of the ingenious efforts which were made from the days of Volta to apply voltaic electricity for the production and transmission of power must necessarily have been futile. The discoveries of Faraday, Hjorth, Pacinotti and Gramme, which culminated in the evolution of the modern dynamo electric machine, have, however, supplied us with an economical source of electric energy, and happily solved the problem of a practical electro motor; for by coupling together two Gramme dynamo electric machines in such a way as to send the current developed by one through the armature of another, the latter will rotate, and become an electro motor. Thus by expending energy in the form of dynamical power in driving the armature of the first machine, we obtain an equivalent of the work done in the form of an electrical current; and by sending this current into the second machine we convert the electricity into energy of motion. In the first case work is transformed into electricity, and in the second electricity is transformed into work. This fact is expressed by saying that electro dynamic machines are reversible. This property of reversibility is among the most valuable discoveries of contemporary science, thus enabling us to complete the theory of electro motors and put them to practical use.

GRAMME'S ELECTRO MOTOR.

Fig. 468 represents the Gramme electro motor, the general appearance of which is similar to that of the large size generator, with the exception that the motor has no current regulator, and that the binding parts are on the front, instead of on the back, as in the larger machines. This is also used to produce a single light of great illuminating power, it being especially designed for currents of great quantity and low electro motive force.

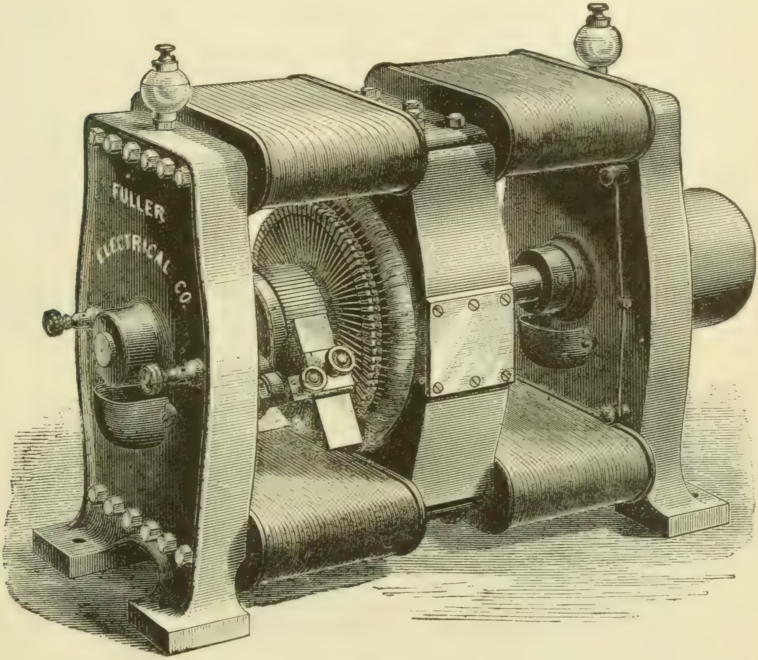


Fig. 468.

BURGIN'S SPHERICAL MOTOR.

In order to avoid remanent magnetism, Dering devised an apparatus consisting of a number of galvanometric helices, the magnetized bars of which reacted upon the same axis, and reversals of the current occurred in the inducing helices at every half revolution of the bars. The motor contained no iron capable of intervening through its remanent magnetism.

With the same end in view, Deprez constructed a machine in which the permanent magnet was replaced by a flat rectangular galvanometric helix, so constructed as to embrace as perfectly as possible the curve of the armature. The changes of direction in the current took place in the galvanometric helix, and, the poles of the armature always remaining the same, there were no ill effects due to remanent magnetism.

Mr. Burgin's spherical motor, represented in fig. 469, is based upon the same idea. The field magnet consists of a spherical shell, around which are horizontally coiled the copper wires, F.

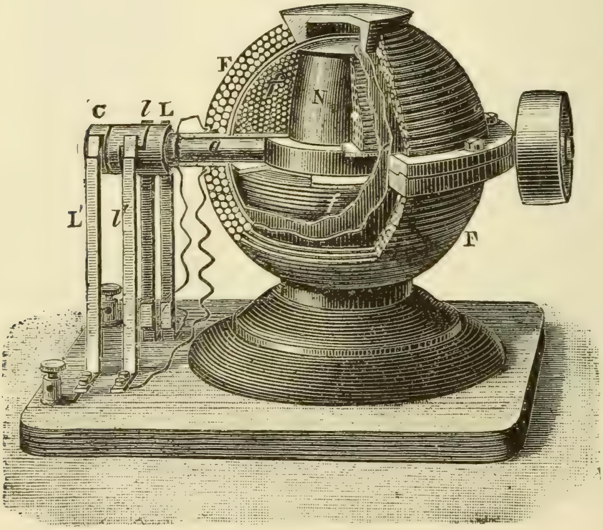


Fig. 469.

In the interior of the hollow sphere a spherical electro magnet, with an iron core, N, revolves around an axis, *a*. The flat springs, L L', press against the solid parts of the commutator in such a way as to send into the wire, *f*, a current always of the same direction; but the springs, *l l'*, through which the current enters the wire, F, rest against the cleft middle part of the commutator, so that at every half revolution the current changes direction in the wire, F, in the same manner as in other motors;

but the reversal of the current takes place in a part containing no iron, and the effects due to the magnetic inertia of that metal are therefore obviated.

DEPREZ' MOTOR.

This apparatus is composed of a horseshoe magnet formed of eight superposed plates. Between the poles of this magnet is a Siemens cylindrical armature, fig. 470, the axis of which is parallel to the arms of the magnet. The core of the armature is a cylinder of soft iron, having two longitudinal grooves in which is rolled the wire that the current is to traverse, and each of the ends of which is connected with one of the semicircles of brass which form the commutator (seen to the right in fig. 470). The current reaches the commutator through brushes made of fine brass wire. The province of the commutator is to cause a change in the direction of the current at every half revolution. The current which traverses the wire of the armature, B, has the effect of forming in the latter two poles of great length, which change character the instant they pass before the poles of the magnet. As the poles of the same name repel each other and those of

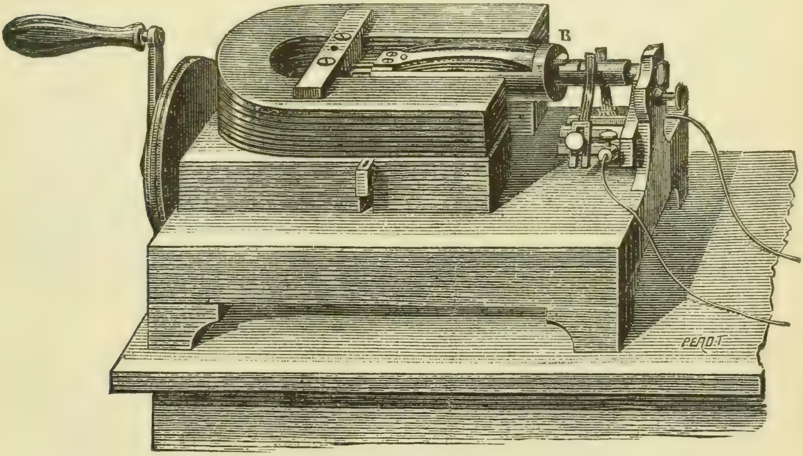


Fig. 470.

different name attract, the armature will assume a rotary motion depending on the direction of the current traversing it. The brushes are mounted on a support capable of turning around the axis of the armature, this arrangement permitting the speed of the motor to be changed without altering its results.

In the small model which is shown in fig. 470, one quarter actual size, the magnet, composed of eight plates, weighs 3¾ pounds, the armature 13 ounces, and the weight of the motor complete, with its base, gearings and brushes, is 9 pounds. The normal velocity of the armature is three thousand revolutions per minute. If the rotation tends to become too rapid, either through an increase of power or a diminution in the amount of work to be performed, a small spring, fixed at one of its extremities with one of the ends of the armature wire and its other extremity resting against one of the sockets of the commutator, springs open from the effect of centrifugal force. The circuit is thus broken, and remains open until the speed again becomes normal. In practice, the opening and closing of the circuit succeed each other so quickly that the variations of speed do not exceed $\frac{1}{700}$ of the normal rate.

GRISCOM'S MOTOR.

This motor, which is four inches long and weighs three pounds, was especially designed for driving sewing machines and other small apparatus. It consists of a Siemens cylindrical armature, fig. 471, revolving between the two poles of an annular electro magnet with consequent points by which it is entirely enclosed and protected. The current is carried to the armature by rollers running on the commutator. In consequence of the annular form of the electro magnet, the armature passes close to the wire which surrounds it, and the induction currents are developed in each half by a pole always of the same name, because the commutator, in consequence of the continuous rotation of the armature, always passes before the helix in the same direction. These currents are, therefore, in the same direction as those which magnetize the field magnet, and tend to augment its power, and the inductive action reaches its maximum at the moment when the axis of the armature makes a right angle with the line which joins the two poles of the field magnet. By this means a powerful magnetic field is obtained, because the intervals during which the axis of the armature is at the greatest distance from the poles, which are to attract it, are utilized to produce the reinforcement of the magnetic field.

This motor may be easily applied to any sewing machine

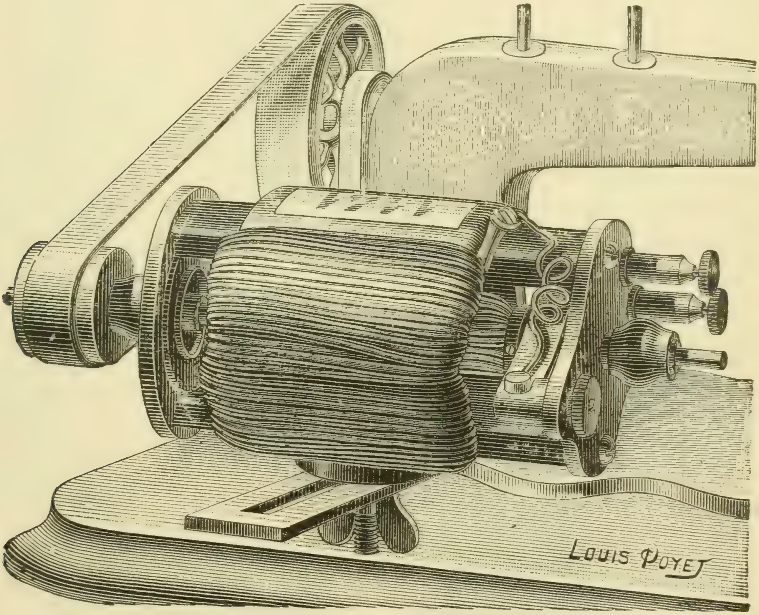


Fig. 471.

already in use, a little straight support, and a nut or thumb-screw under the motor, fig. 471, being sufficient to fix it in place.

The electric generator employed is a bichromate of potash battery of six cells, contained in a box which serves for a seat for the operator, and by means of a foot pedal, conveniently placed, the battery plates may be depressed into the liquid in the cells or raised out of it, and the speed of the motor thereby regulated. The battery contains a sufficient quantity of liquid to sew 1000 yards of seams at any time within six months.

DEPREZ' ELECTRIC POWER HAMMER.

The essential part of this apparatus, which is shown in fig. 471, is a sectional solenoid, which is constructed by superposing a hundred flat bobbins, half an inch in thickness, upon each other, in such a way as to form a single solenoid three feet in height; the incoming and outgoing wires of each of them being connected with the contiguous bobbins in exactly the same way as they are in the consecutive sections of a dynamo electric machine. Each junction of the wire of one of the coils with the wire of its neighbor ends in a metallic plate set into an insulating piece containing one more plate than there are coils. Over this species of collector, which may be rectilinear or cylindrical, pass two brushes fixed to an insulating piece that may be moved by hand. If these two brushes are placed at a distance so that the number of the plates of the collector included between them be, for example, equal to ten, and they are then given any degree of displacement whatever, after rendering them interdependent, the current which enters through one of these brushes and makes its exit through the other will always traverse ten coils. The effect will be the same as if the ten bobbin solenoids were moved instead of the brushes. If now a current is sent into the apparatus and a soft iron cylinder be placed therein, the cylinder will remain suspended in the interior of the solenoid, its longitudinal centre tending to place itself at a distance from that of the solenoid in proportion to the intensity of the current. It would fall out if the intensity of the current decreased beyond a certain point. If the current is intense enough to keep the distance of the two centres much below that which would bring about a fall of the cylinder, and an attempt is made to remove the latter from the equilibrium that it is in, a pressure must be applied that increases with the amount of separation, exactly as if suspended from a spring. If we displace the brushes a distance equal to the thickness of one plate of the collector, the active solenoid will undergo the same displacement, and its longitudinal centre will move away from the iron cylinder, and the

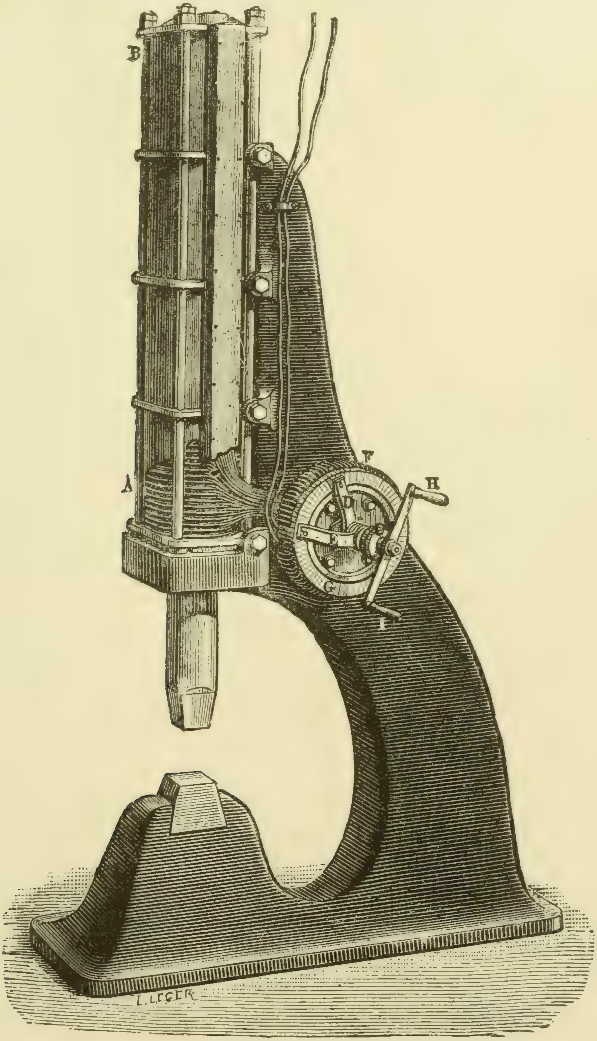


Fig. 472.

attraction exerted upon the latter will increase. Equilibrium cannot be re-established unless the cylinder undergoes a displacement identical with that of the solenoid, and as the latter depends upon the motion communicated to the brushes, the cylinder will faithfully reproduce the motion communicated to them by the operator. Everything takes place as if the iron cylinder were suspended in a solenoid four inches in length that was caused to rise and fall, with the difference that the weight of the cylinder exerts no action on the hand of the operator.

The elementary sections constituting the electric cylinder, A B, of the hammer are 80 in number, and form a total length of one meter. Their ingoing and outcoming wires end in a collector of circular form shown at F G. The brushes are replaced by two strips, C E and C D, fixed to the double winch, H C I, which is movable around the fixed centre, C. They can make any angle whatever with each other, so that by trial the most suitable length may be given to the active solenoid. When such angle has been determined, the angle, E C D, is rendered invariable by means of a set screw, and the apparatus is manœuvred by imparting to the double winch, H C I, an alternating circular motion.

The iron cylinder weighs 50 pounds; but when the current has an intensity of 43 ampères and traverses 15 sections, the stress developed may reach 150 pounds, or three times the weight of the hammer.

THE ELECTRICAL TRANSMISSION OF ENERGY DERIVED FROM NATURAL SOURCES.

In 1877 Sir William Siemens, in delivering an address before the Iron and Steel Institute, said that time would probably reveal to us effectual means of carrying power to great distances, and alluded, as particularly worthy of consideration, to the use of an electrical conductor to convey the power of a waterfall employed to give motion to a dynamo-electrical machine, developing a very powerful electrical current, which could be carried to a great distance through a large metallic conductor, and then be made to impart motion to electro magnetic engines, to ignite the carbon points of electric lamps, or to effect the separation of metals from their combinations. A copper rod three inches in diameter he claimed would be capable of transmitting one thousand horse-power a distance of three miles, an amount sufficient to supply one quarter of a million candle power, which would suffice to illuminate a moderately sized town. Sir William Thomson at once accepted these suggestions, and with the conceptive ingenuity peculiar to him, went far beyond Siemens in showing before the Parliamentary Electric Light Committee of 1879 that, through a copper wire of only half an inch in diameter, twenty-one thousand horse-power might be conveyed to a distance of three hundred miles with a current of an intensity of 80,000 volts. The time may come when such a current, which would have a striking distance of about fourteen inches, may be practically used, but then, probably, a very practical law enumerated by Sir William Thomson would be infringed, viz.: that electricity is conveyed at the cheapest rate through a conductor, the cost of which is such that the annual interest upon the money expended equals the annual expenditure for lost effect in the conductor in producing the power to be conveyed. As Sir William Siemens' suggestion was much criticised at the time it was made, when it was still thought that electricity was incapable of being massed so as to deal with many horse-power of effect, and the size of the conductor he proposed was also considered wholly inadequate, it will be interesting to test his early calculation by recent experience. Mr. Marcel Deprez, as is well known, has succeeded recently in transmitting three horse-power to distances of twenty-five miles through a pair of ordinary telegraph wires of No. 8 B. W. G. gauge. Taking the relative conductivity of the iron wire employed by Deprez, and the three inch copper rod proposed by Siemens, the amount of power that could be transmitted through the latter would be about four thousand horse-power. But Deprez employed a motor of 2,000 volts, and was contented with a yield of 32 per cent. only of the power imparted to the primary machine, whereas, Siemens calculated upon an electro-motive force of 200 volts, and upon a return of at least 40 per cent. of the energy imparted. Sir William Armstrong, in the year 1878, was probably the first to take practical advantage of Siemens' suggestions, in lighting his house at Craigside at night, and working his lathe and saw bench during the day, by power transmitted through a wire from a waterfall nearly a mile distant. Sir William Siemens also for several years pumped water, cut wood, hay and swedes, lighted his house, and carried on experiments in electro horticulture by electric energy derived from a common centre of steam power, with the most satisfactory results; the whole management having been in the hands of a gardener and laborers, who were without previous knowledge of electricity, and the only repairs that were found necessary were one renewal of the commutators and an occasional change of the metallic contact brushes.

QUARTERNARY TRANSMISSION OF FORCE.

In the month of March, 1883, Sir William Siemens gave an exhibition of electrical transmission and storage of power before the Institution of Civil Engineers in London.

In a yard adjoining this institution a portable steam engine had been erected giving motion to a dynamo electric machine capable of developing about 8 horse power of electrical energy, or $746 \times 8 = 5{,}968$ watts. This power was conveyed through an insulated wire to the coils of an electro-motor, the rotating axis of which was practically in one piece with that of a centrifugal pump, by which water could be raised in considerable quantities, and when forced through a nozzle could be lifted sixty feet high. The mechanical effect thus realized amounted to about four horse power, and the experiment was interesting as showing a practical application of electric energy to useful purposes. Considering that the weight of the machine and pump was less than half a ton, and that the power could be easily augmented to five or six horse power, it is not unreasonable to look forward to the time when our fire engines will be worked on this principle. Sir William Siemens next turned the current from some storage batteries upon the machine in order to produce the same results. In this instance the effect, originally produced by the steam engine, had given motion to a dynamo electric machine, the electricity from which had been transferred to the secondary battery, where it had produced chemical action. The store of chemical effect thus produced within the battery was now made available in forming a current, which, passing through the electro dynamic motor connected with the pump, imparted motion to the latter. The current was then connected with a second electro dynamic motor to work a saw bench, giving motion at the same time to a dynamo electric machine, wound with comparatively thick wire. The potential of the dynamo electric machine outside of the building was equal to one hundred volts, but it is sometimes inconvenient to use a current of such high tension, and the object in transferring the power derived from the machine of high potential to the machine wound with thick wire was to obtain a current of low potential, which in this instance did not exceed ten volts. Such a current could not harm a child, but is most effective where quantity rather than high potential is required, as, for instance, for electrolytic purposes. The current from this machine, which Dr. Siemens called the tertiary, and showed to be more effective than either the primary or secondary in heating an iron wire of considerable thickness, was then connected to a little toy railway, which was thus propelled by a quarternary transmission of force. The steam engine transferred its energy to a dynamo electric machine; this dynamo electric machine gave motion to an electro dynamic motor; this electro dynamic motor transferred its power to another dynamo electric machine, and this again gave motion to the carriage upon the rails, which latter performed the function of conducting wires. The same power had thus been four times transmitted, showing the great facility with which we can reconvert it again and again from mechanical into electrical, and from electrical into mechanical effect, and alter its character from a current of high potential to a current of low potential, or vice versa.

Dr. Siemens next described an application of electricity lately made by Dr. John Hopkinson to an electrical hoist, which was to be placed at the top of a warehouse, and by putting on the current of the dynamo-machine the weight could be lifted readily, and stopped and lowered at will according to the position of the brushes upon the dynamo commutator.

Another application which has been made with great effect is that of raising the wire which is used in sounding by Sir William Thomson's wire-sounder. The machine has been employed on board the Faraday, and the wire drawn up in an extraordinarily short space of time. By these means soundings can be made in 2,500 fathoms in an hour, because the steamer can go on while the electric machine is pulling in the wire. The only drawback which was found in the early trials was that the machine having been placed near the compasses, the latter was influenced magnetically; the caution, therefore, to be observed, is to put it in a part of the ship away from the compasses.

When losses by unnecessary wire resistance, by Foucault currents and by induced currents in the rotating armature, are avoided, as much as 90 per cent., or even more, of the power communicated to the machine is realized in the form of electric energy, and, vice versa, the reconversion of electric into mechanical energy can be accomplished with similarly small loss. Thus, by means of two machines at a moderate distance apart, nearly 80 per cent. of the power imparted to the one machine can be again yielded as mechanical energy by the second, if we leave out of consideration frictional losses, which latter need not be great, considering that a dynamo machine has only one moving part well balanced, and is acted upon along its entire circumference by propelling force. Jacobi proved, many years ago, that the maximum efficiency of a magneto electric engine was obtained when

$$\frac{e}{E} = \frac{w}{W} = \frac{1}{2}$$

which law has been construed by Verdet and others, to mean that one-half is the maximum theoretical efficiency obtainable in electric transmission of power, and that one-half of the current must be necessarily wasted or turned into heat. Dr. Siemens, who could not be reconciled to a law necessitating such a waste of energy, maintained, without disputing the accuracy of Jacobi's law, that it has reference really to the condition of maximum work accomplished with a given machine, whereas its efficiency must be governed by the equation

$$\frac{e}{E} = \frac{w}{W} = \text{nearly } 1.$$

From this it follows that the maximum yield is obtained when two dynamo machines, of similar construction, rotate nearly at the same speed, but under these conditions the amount of force transmitted is a minimum. Practically the best condition of working consists in giving to the primary machine such proportions as to produce a current of the same magnitude, but of 50 per cent. greater electro motive force than the secondary; by adopting such an arrangement, as much as 50 per cent. of the power imparted to the primary could be practically received from the secondary machine at a distance of several miles. Professor Thompson, in his recent Cantor Lectures, has shown an ingenious graphical method of proving these important fundamental laws.

SIEMENS' ELECTRIC RAILWAYS.

The idea of superseding the steam locomotive by an electric engine is by no means a novel one; an electric locomotive having been devised in this country in 1847 by Mr. Lilly and Dr. Colton of Pittsburg. The locomotive was placed upon a circular railway, around which it was driven by electricity. The rails were insulated and each connected to a pole of the battery—the current being communicated to the engine through the wheels. The engine was provided with two magnets, which, by a process of alternate attraction and repulsion, drove the car over the track.

In connection with the history of this subject it is worth while also to mention that M. Boué, of Belfort, France, took out a patent in 1878 for the propulsion of carriages on a railway by means of electricity; and that not only did the patent describe a means for driving a single train of cars, but also a vibratory apparatus whereby the power of the current may be distributed to several separate trains so as to propel them all. But while historical mention is justly due to the pioneers of a new invention, the chief merit rests with him who makes it a success, and the electric railway was never practically realized until 1879, when Dr. Werner Siemens built and operated an electric tramway in the grounds of the Industrial Exhibition at Berlin. To Dr. Werner Siemens, therefore, belongs the honor of recognizing that the improved means now at our disposal for generating electricity and applying it to the transmission of power are sufficient to operate an electric railway on a practicable scale.

THE BERLIN ELECTRIC RAILWAY.

The Berlin railway was a narrow gauge line, laid down in a circle 900 yards long. A train of three cars was placed upon it, and on the first car a medium-sized electro dynamic machine was fixed to the axle of one pair of wheels in such a manner as to rotate the wheels when the armature of the machine was revolved by the passage of a current through its coils. Acentral rail, supported upon insulating blocks of wood, ran between the two working rails, and it was by this central conductor that the current was led from the generating machine placed at one terminus of the line. The current was drawn from this rail to the armature of the machine on the locomotive by means of a brush of copper wires; and after traversing the coils of the armature it was led to the axle of the driving wheels, which was insulated from the body of the car, and thence by the driving wheels to the outer rails, and by them back to the dynamo electric machine at the terminus.

Fig. 473 represents a section through the locomotive, showing the electro dynamic machine, B, and the central rail, N, with the metal brush for picking up the current.

Between twenty and thirty persons could be accommodated on the train at a time, including the conductor, who rode on the first carriage; and during the course of the summer no fewer than 100,000 were conveyed over the line, at a speed of from fifteen to twenty miles an hour. Crowded trains left the stations every five or ten minutes, and a considerable sum was earned in this way for the benefit of charitable institutions. The locomotive was capable of exerting five horse power, and instead of being fitted with a steam valve like a locomotive to start or stop it, it was simply provided with a commutator for closing or opening the circuit of the current.

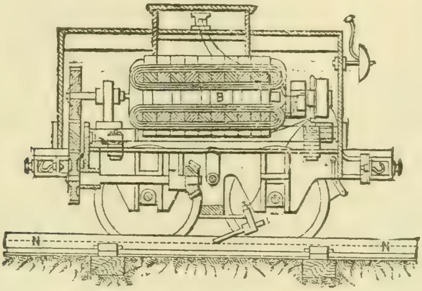


Fig. 473.

THE LICHTERFELDE ELECTRIC RAILWAY.

The success of this experiment soon led to the laying of the Lichterfelde line, in which both rails were placed upon insulating sleepers, so that the one served for the conveyance of the current from the power station to the moving car, fig. 474, and the other for completing the return circuit. This line has a gauge of 3 feet 3 inches, is a mile and a half long, and is worked by two dynamo electric machines, developing an aggregate current of 9,000 watts, equal to 12 horse power. It has been in constant operation since the 16th of May, 1881, and has never failed in accomplishing its daily traffic.

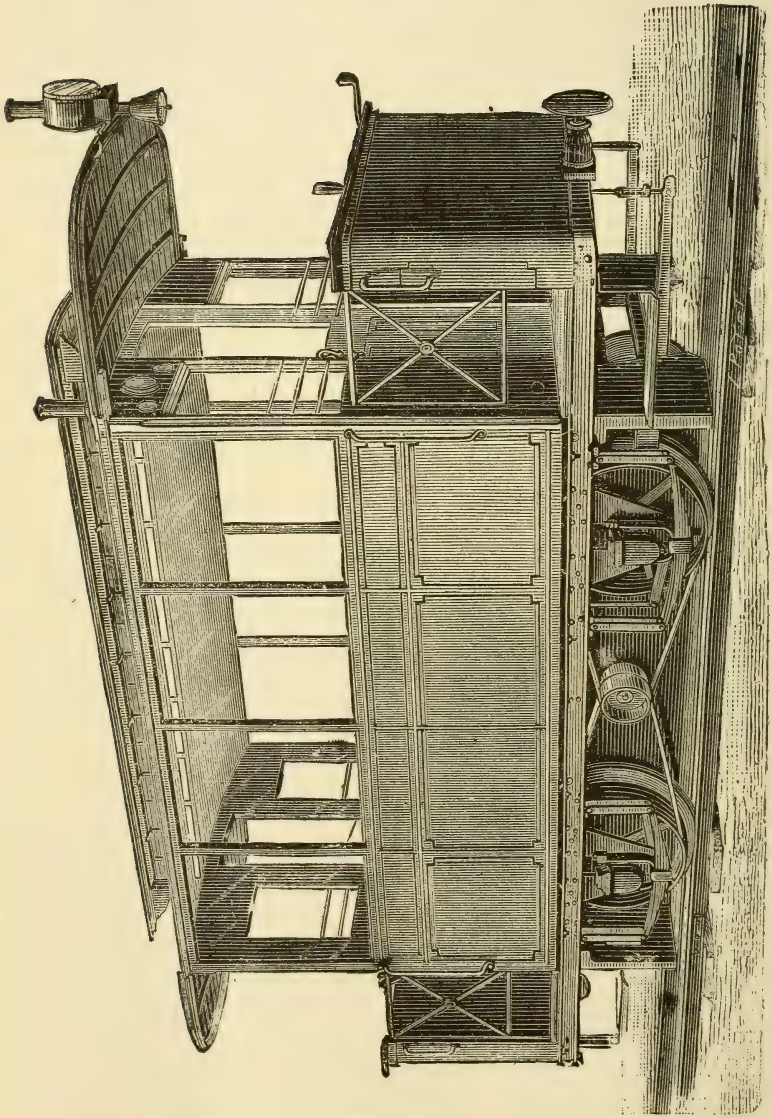


Fig. 474.

THE PARIS ELECTRIC RAILWAY.

A line one-third of a mile in length, but of four feet eight and a half inches gauge, was established at Paris in connection with the Electric Exhibition of 1881. In this case, two suspended conductors, in the form of hollow tubes with a longitudinal slit, were adopted, the contact being made by metallic bolts drawn through these slit tubes, and connected with the dynamo electric motor on the moving car by copper ropes passing through the roof.

This electric tramway, which was in successful operation during the entire summer of 1881, experimentally confirmed the good results obtained at Berlin and Lichterfelde. Although the line was not constructed in strict accordance with the requirements of a permanent electric railway, designed for practical use, the experiment was none the less satisfactory, and the difficulties which had to be overcome at the commencement of the enterprise proved the fecundity of resources which electricity places at our disposal. Mr. Siemens had devised a system for use in cases where the rails could not, as in Lichterfelde, serve as sole conductors. This arrangement consisted in a movable contact rolling upon an aerial conductor, supported from point to point upon poles, the rails serving as a return wire. This mode of communication, which was then but partially developed, was the one which had been selected to be put in practice at the International Electrical Exposition. Mr. Siemens had at first intended to establish an elevated railway, supported upon columns, but as the authority required to do this was accorded too late for the completion of the work in time for the exhibition, he was compelled to build a surface line. He was not, however, permitted to place the rails in relief, as he had done at Lichterfelde, and was finally obliged to arrange for the use of rails laid even with the earth, like those of an ordinary tramway. This last circumstance was another serious obstacle to the accomplishment of the enterprise which had to be overcome. In the preliminary experiments made at the workshops, they employed a brass tube which was electrically connected with the car by a traverser, to bring the current from the dynamo electric machine to the electro dynamic motor, and the wheels and rails served as a return conductor. This system, which worked well in the workshops, encountered a special difficulty in practice. The dirt, sticking to the rails and felloes of the wheels, formed a sort of insulating crust, which prevented a sufficiently good contact between the car and the rails to permit of the latter serving as a return conductor. Mr. Siemens was compelled, therefore, to establish two aerial conductors, instead of one, and to provide also two movable contacts. These unforeseen modifications occasioned some delay in the construction of the tramway, but the necessary appliances were at last successfully devised and executed, and the system of movable contacts, practically employed for the first time upon the Place de la Concorde, was entirely satisfactory. We will first describe this system, and point out afterward the particularities which accompanied the vehicle in its practical application.

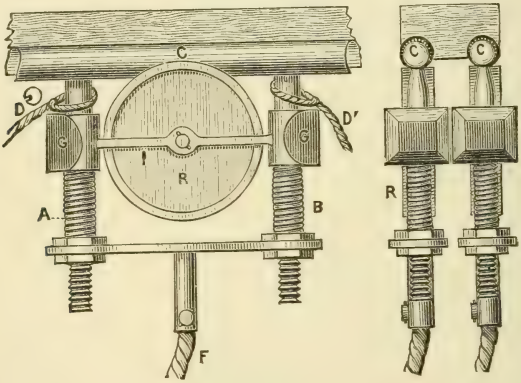


Fig. 475.

The stationary aerial conductors were composed of brass tubes, C, represented in longitudinal and transverse section in fig. 475. These tubes were fastened to wooden bars, supported on poles by a system of iron wires analogous to those which are employed in suspension bridges. The tubes, C, were slit on their lower part along their length to a width of about $\frac{1}{16}$ of an inch. In the interior of each of these tubes slid a sort of shuttle made of brass, five inches in length, from which depended two vertical shafts. Upon these shafts slid a cross-bar carrying a wheel, R. A second cross-bar was fixed below between two screw nuts at the extremity of the two shafts, and upon this cross-bar rested two spiral springs, A B, which tended to raise the upper cross-bar, G G, which supported the wheel or roller, R, so that the wheel pressed constantly upon the tube and thus maintained an elastic contact between the wheel and the tube. Thus there was a constant connection between the wheel R and the shuttle inside of the tube C; and, consequently, between the tube and the movable system there was an unbroken contact which, if not perfect, was at least always practically sufficient. Occasionally a few sparks were seen when the shuttle passed over a coupling in the tubes, which were due to small instantaneous ruptures of the current, but which did not affect the working of the system.

The two tubes were connected at their farther ends near the Palais de l'Industrie to two conductors coming from the dynamo electric machine, which generated the current; and from the movable contact piece, or shuttle, departed an insulated wire, F, which was connected with the electro dynamic motor, situated under the car between the wheels, to which it transmitted its motion by means of a gall chain. These were not, however, the two wires which, during the progress of the car, affected the traction of the movable contact apparatus. For this purpose, to each contact two cords, D D^1, were attached to the vertical shafts above the cross bar, G G, each of them serving to draw the movable contact according to the direction of the car, and there were also four cords for connecting the car with the whole of the two movable contacts. In order to prevent their touching and forming an electrical contact during their movement, the extremities of the cross bar, G G, were provided with pieces of ebonite, which effectually prevented all accidents of this nature. In practice, the various pieces forming the movable contact suffer more or less from wear and tear, but experience has shown that the wear comes especially upon the shuttle, or core, which is easily replaced.

The maximum speed which the vehicle was able to attain was 40 miles an hour; but its average speed, during the whole time that it was in operation, was 10½ miles an hour. In order to regulate the speed, the conductor of the car had conveniently at hand the lever of a rheostat, by which he could introduce more or less resistance into the circuit. The lever, which was placed horizontally at the end of the car, moved over contact segments arranged in a circle. These segments, which were insulated from each other, were connected by coils of wire whose resistances ranged from one ohm to two hundred ohms each. The stoppage of the car was produced by the interruption of the circuit, but, in order to prevent a too sudden rupture of the current, this interruption was preceded by the introduction in the circuit of a very large resistance. For this purpose, the conductor moved the lever of his commutator in such a manner as to gradually increase the resistance; when the lever had arrived at the end of its course, the current was broken. In addition to the above mentioned appliances, the car was also provided with an ordinary brake, which also contributed to its stoppage.

The number of revolutions of the dynamo electric generator was 550 per minute, and that of the electro dynamic motor, placed under the car, was 465 per minute. The line had a total length, from the Palais de l'Industrie to the little shed situated at the corner of the Champs Elysees, of about one third of a mile. It had a curve of 61 yards radius, and from the entrance of the Palais to the point where it passed the fountain, a second curve of 33 yards radius, with a counter curve nearly identical. At one point there was a grade of an inch per yard. Upon the straight part of the line, the work expended at the average speed was three and a half horse power; upon the curve, it was seven and a half horse power, and it reached more than eight and a half horse power upon the ascending grade.

The car differed a little from that of the electric tramway at Lichterfelde, it being an imperial car, modelled after that of the

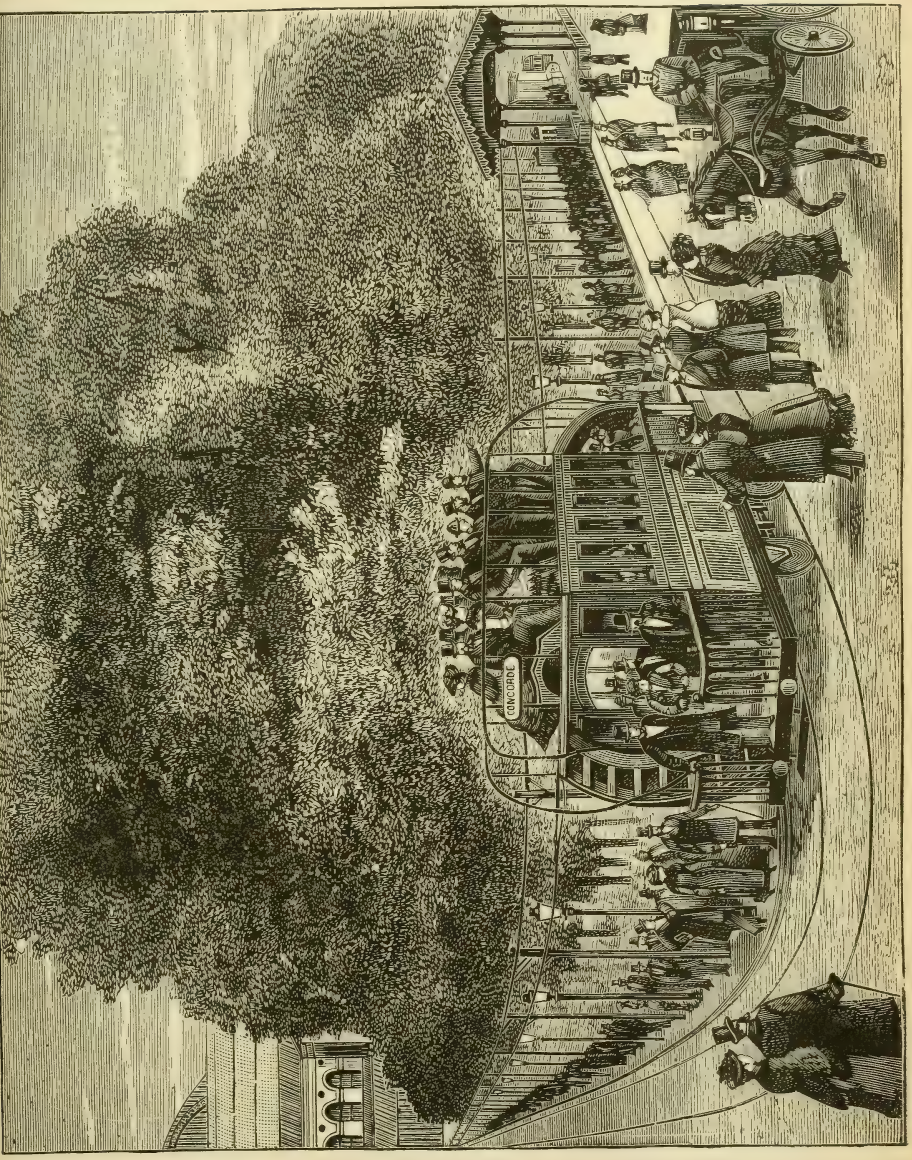


Fig. 476.

North Tramways, and it was capable of containing 50 persons, including the controller and conductor. The car weighed, when empty, 12,000 pounds; and when filled, it attained a weight of 20,000 pounds. It is represented in fig. 476, which also gives a general view of the line.

During the continuance of the Electrical Exposition, a period of about seven weeks, 95,000 passengers were conveyed on this line, and its good working produced a new proof of the practicability of electric railways. The administration charged five cents for the conveyance of each passenger from end to end of the railway, and the amount received was sufficient to pay all expenses.

Concerning the mode of communication adopted, although it worked satisfactorily at the Exposition, it is evident that it would not be applicable to lines of much greater length. For long distances it will be necessary to employ lines raised above ground, like those at Lichterfelde, or elevated ones like those projected by Mr. Siemens, where its rails can be utilized as conductors. But, on the other hand, the movable contacts, the efficiency of which has been fully recognized at the Champs Elysees, will be able to render service in other cases. In works of exploitation, for example, as in the galleries of mines, and in short, for all lines of small extent, where it would be difficult to insulate the rails, recourse might be had to them.

THE PORTRUSH ELECTRIC TRAMWAY.

An electric tramway, 6 miles in length, has been constructed between Portrush and Bush Mills, in the north of Ireland. In this instance the two rails, 3 feet apart, are not insulated from the ground, but being joined electrically by means of copper staples they form the return circuit, the current being conveyed to the car through a T iron placed upon short standards, and insulated by means of insulite caps. Where a gap necessarily occurs, such as at a cross road, they simply stop the T iron and commence it again at the other side of the gap, connecting the two ends by means of an insulated conductor below ground.

In order to span the gap two brushes are attached to the car, one in front and the other toward the back of the car, and the gap being a little less than the distance between the two brushes, the one brush catches the opposite side before the other one leaves. Thus by a simple arrangement they get over the difficulty of crossing by-roads. At first the power was produced by a steam engine at Portrush, giving motion to a shunt-wound dynamo of 15,000 watts = 20 horse power, but arrangements were subsequently made to utilize a waterfall of ample power near Bush Hills, by means of three turbines of 40 horse power each. The working speed of this line is restricted by the Board of Trade to 10 miles an hour, which is readily obtained, and there is no difficulty in starting the loaded car on the worst part of the route, which a steam engine frequently fails to do. At one point there is a long and rather steep incline—1 in 38—two miles in length. There was some doubt in the mind of Sir William Siemens, the constructor of the line, whether, with the arrangements adopted, this incline could be worked satisfactorily; but experience has proved that it could be, and the car is drawn up the incline without difficulty when fully loaded. It may, therefore, be said that transmission or propulsion by electricity, even under adverse circumstances, is an accomplished fact. A further six miles of extension to Dervock will connect this railway with the railway system of the north of Ireland; they will then have a length of twelve miles of line of the same gauge, and using the same carriages as those generally used there.

It is a remarkable circumstance in favor of the electric transmission of power, that while the motion of the electro dynamic or power receiving machine is small, its potential of force is at its maximum, and it is owing to this favorable circumstance that the electric train starts with a remarkable degree of energy. With the increase of motion the accelerating power diminishes until it comes to zero, when the velocity of the electro dynamic or driven machine becomes equal to that of the dynamo electric or current producing machine. Between the two limits of rest and maximum velocity the driving power regulates itself according to the velocity of the train: thus, on an ascending gradient the speed of the train diminishes, but the same effect is automatically produced which results from the turning on of more steam in case of the locomotive engine. When running on the level, the velocity of the train should be such that the magneto electric machine should make one half to two thirds of the number of revolutions per minute of the dynamo electric machine. When descending, the speed of the electro dynamic machine will be increased in consequence of the increased velocity of the train, until it exceeds that of the dynamo electric machine, from which moment the functions of the two machines will be reversed; the machine on the train will become a current generator, and pay back, as it were, its spare power into store, performing at the same time the useful action of a brake in checking further increase in the velocity of the train. If two trains be placed upon the same pair of rails, the one moving upon an ascending portion, the other upon a descending portion of the same, power will be transmitted through the rails from the latter to the former, and they may, therefore, be considered as connected by means of an invisible rope.

With regard to the relations of work done to energy expended on the electric railway, the proportion of power actually transmitted varies with the speed of the train, and reaches a maximum when the angular velocity of the armature of the machine on the train is about two-thirds that of the armature of the current generator. Under this condition it is found in practice that something over fifty per cent. of the motive power of the stationary engine driving the generator is utilized in drawing the train.

It is not to be expected that the electric locomotive will compete with the steam locomotive on long lines of railway, but it may prove very serviceable under special circumstances and on short lines. For steep gradients, tramways in mines, docks, large works, or cities, it is particularly well adapted, owing to its freedom from noise or noxious fumes. It is also well adapted for the transmission of letters along subterranean tubes.

TRAMWAY WORKED BY ELECTRIC ACCUMULATORS.

For tramways within populous districts the insulated conductor involves a serious difficulty, and it may, perhaps, be more advantageous under these circumstances to resort to secondary batteries, forming a store of electrical energy carried under the seats of the car itself, and working an electro dynamic motor connected with the moving wheels.

Such an experiment has recently been made at Kew Bridge, on the Acton tramway line, London. The car used in this experiment was fitted with an accumulator battery consisting of 50 Faure-Sellon-Volckmar cells, weighing about 80 lbs., and capable of working a tram car with its full load for seven hours. The accumulators were stored under the seats of the car, and the current was conveyed by insulated wire to a Siemens electro motor, the armature of which being revolved, and the power was conveyed to a pulley fastened on the same axle as the armature and connected with the axle of the driving wheel. The motor worked satisfactorily with an electro motive force of 100 volts, producing a current of 60 ampères, equal to 6,000 watts, and as 746 watts constitute a horse power, the result was a consumption of eight horse-power.

By means of a simple switch the action of the motor was reversed at will, and the power increased or diminished as required, by adding to or taking from the number of cells composing the accumulator, and by breaking the circuit the motive power was stopped, and the brake being then applied, the car was almost immediately brought to a standstill.

The car could carry a load of forty-six persons, the total weight being about five tons. The speed attained was six miles per hour, and the car ran smoothly along a level road and down hill. When the attempt was made to ascend an incline, a defect in a connecting band interfered with the operation of the motor, and the trial was interrupted at that point. There is believed to be, however, no serious difficulty involved in the case, and it was decided to place electrical cars on the Acton road as soon as the necessary license could be obtained.

The cost of running cars in this manner is estimated at $1.50 per day for each car, against $6.25 for the same service when horses are employed, and in places where water or other natural power is available, and there would be no expense for fuel, the outlay would be still more favorable to the new system. It should be stated as another advantage of this electrical car that it was lighted by Swan incandescent lamps, and supplied with electric bells, both being worked by the accumulators.

AN ELEVATED ELECTRIC TRAMWAY.

Dr. Werner Siemens has designed an elevated tramway to connect one end of the city of Berlin with the other. It is proposed to have two separate lines, one for the going and the other for the return journey. The rails are to be 3 ft. 3 in. apart, and only two rails will be required for each line, the current coming from the terminal engine by one line, and returning by the other. Each train has fourteen narrow cars, four to convey standing passengers, and ten for sitting passengers. A 60 horse power engine will be stationed at one end of each line, and the speed will be twenty miles per hour.

ELECTRIC RAILWAY IN TUNNELS.

The freedom of the electro locomotive from smoke is of great importance in passing through a long adit or tunnel, and it is interesting to learn that the administration of the St. Gothard Tunnel seriously contemplate its application to the conveyance of their trains through that gigantic tunnel. Existing circumstances are in this case favorable to the employment of electric power, as at both ends of the tunnel turbines of enormous aggregate power were established to assist in boring, and still stand ready for use. All that has to be done, therefore, is to insulate the rails, and connect dynamo electric machines of sufficient power to the turbines and the train. Instead of insula-

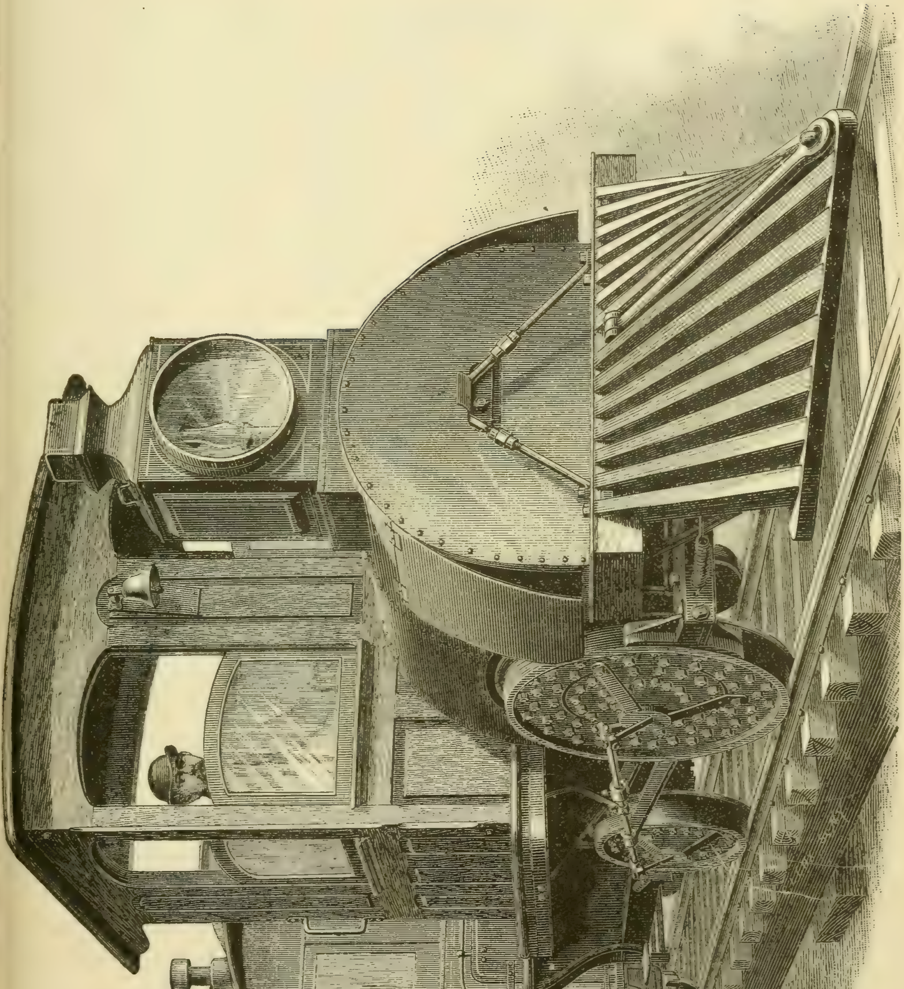


Fig. 477.

ting one of the rails, it might be advisable to convey the current by a conducting rope resting on wooden or glass supports in such a manner that it can be picked up by the train as it passes, and run over one or more contact pulleys connected to the armature of the machine carried by the train, then deposited again on its insulating supports. In this way, no doubt, the insulation of the rails could be avoided, but it remains to be determined by the experiment whether the high velocity of the train would not render such a plan impracticable.

EDISON'S ELECTRIC RAILWAY.

Fig. 477 presents a general view of an electro motive engine and car devised by Mr. Thomas A. Edison, and was employed by him in 1880, at Menlo Park, N. J. This electric railway was built upon natural ground, with little or no grading or regard for curves, and was about half a mile in length. The motor was precisely like the electric generator shown on page 138, and the current was supplied by a similar machine worked by a stationary engine. The current was conveyed to the track by two copper wires, one being connected to each rail, the rails being insulated from each other. The armature of the locomotive made four revolutions to one revolution of the driving wheels.

FIELD'S ELECTRIC RAILWAY.

An electric railway, devised by Mr. Stephen J. Field, was exhibited at the Chicago Exposition in 1883, on which occasion two of Weston's No. 6 dynamo electric machines were employed, the same type being used as a generator and motor. The track, fig. 478, was laid in the gallery of the main building, extending around its margin and curving sharply at either end on a radius of 56 feet. Its total length was 1,553 feet, or nearly one third of a mile. This track, which was of three feet gauge, was composed of three rails, as in Siemens' Berlin line, the middle rail being connected with one pole of the stationary generator located below on the main floor, at a distance of about fifty feet

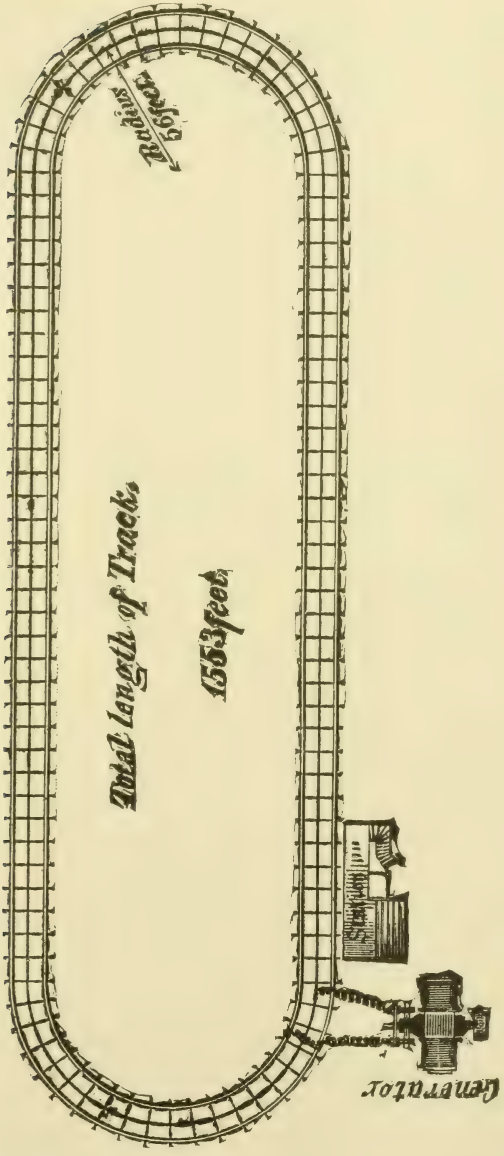

Radius
56 feet
Total length of Track
1553 feet
Station
Generator

Fig. 478.

from the track. The two outside tracks were electrically connected together and with the other pole of the generator. This arrangement obviated the necessity of insulating the wheels on one side from those on the other, which is necessary when only two rails are used. In order to secure good connections and low resistance, a precaution made necessary by the low electro motive force of the generator, wires were laid under each rail. The locomotive, which was twelve feet long and five feet wide and weighed about three tons, is shown in Fig. 479 in plan with its cab removed. This figure shows the manner of transmitting the power from the armature of the motor to the driving wheels. The motor is placed crosswise upon the frame. Its armature shaft is coupled to an extension shaft which is prolonged forward and transmits motion by means of bevel gearing to a countershaft carrying two pulleys. From these pulleys the power is transmitted by means of belts to the loose pulleys on the axle of the drivers. The gearing of the armature extension shaft to the counter shaft was made so as to reduce the speed three times. The pulleys on the counter shaft were 12 inches in diameter, the driven or loose pulleys on the axle of the driving wheels were 26 inches in diameter, and the driving wheels were 30 inches in diameter. The maximum speed which this gearing would produce was about 12 miles per hour, but the weakness of the gallery on which the track was laid made it necessary to run the locomotive at a lower speed. The average speed maintained was eight miles an hour, the motor revolving at the rate of about 750 turns.

The two Weston machines used as generator and motor were of the shunt wound description, in which the current from the armature divides into two portions, one passing through the field magnet circuit and the other through the external circuit, the amount of current flowing through each circuit being inversely proportional to its resistance. When the resistance of the external circuit is great, a large amount of current passes through the field magnet, and the magnetic field is stronger. In this case the effect of opening the external current is precisely the same as if its resistance were increased to infinity; that is to say, all of the current passes through the field magnets and the magnetic field attains its highest degree of power. On the other hand, when the resistance of the external circuit is reduced to almost nothing, the greater part of the current passes through the external circuit, only a small portion passing through the field magnets, and the magnetic field is very weak. Consequently, if a shunt generator is started with a closed external circuit of very low resistance, the small quantity of current induced in the armature by the residual magnetism of the magnetic field passes almost wholly into the external circuit, and the magnetism of the magnetic field fails to increase, so that the current developed remains small.

Now if, as in the case of the electric locomotive, the external circuit consists of a second machine to be worked as a motor, the resistance of which is very small, the generator will not develop current enough to start the motor. If, however, the leading wires add sufficient resistance to the external circuit to cause the diversion of an appreciable current into the derived or field magnet circuit of the generator, its magnetic field will increase in power and the current induced in the armature will consequently be greater in volume, and perhaps enough to start the motor. Consequently it would appear expedient to increase the external resistance at the time of starting the generator, so that its magnetic field may be charged sufficiently. When the motor begins to move it develops a counter electro motive force in the circuit which practically amounts to so much electrical resistance, and causes the further diversion of current into the magnetic field circuit. Thus, when once started, the counter electro motive force of the motor answered the purpose of resistance. It was found by experiment that the best efficiency of the generator was realized when the motor had attained its maximum speed, from which it was inferred that the proper moment to put the load on the motor was when it had reached its greatest velocity.

The mechanism by which this was accomplished is shown in fig. 480, which represents a rear end elevation of the locomotive without the cab. The loose pulleys, G G, run on the axle of the driving wheels, W W, motion being transmitted to them

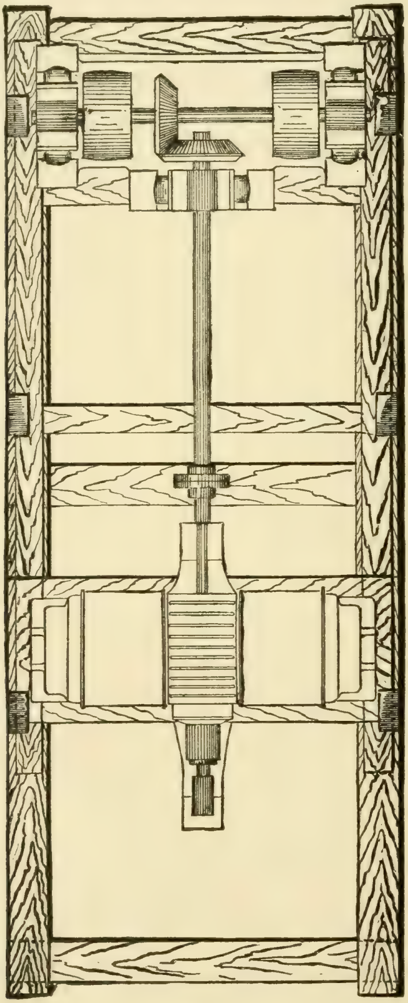


Fig. 479.

by belts from the pulleys of the countershaft, as shown in figs. 3 and 4. F F F F are cone friction pulleys fitting into the interior of the rim of the loose pulleys. These friction pulleys revolve with the shaft, being connected thereto by means of keys and key-ways, which are loose, however, so that the friction pulleys can slip lengthwise on the axle as they revolve. The hub of each friction wheel, F_1 F_1, carries a collar, E E, which is connected by arms, D D, to a lever, B, fulcrumed at C on a projection from another collar fitted around the shaft. In the position shown the friction cones F F F_1 F_1 are removed from the pulleys, which are free to move loosely upon the axle. But upon moving the lever B to the right the friction cones both move outward from the centre, and engage the inner surface of the pulleys, and thus the motion of the loose pulleys is communicated to the driving wheels W W.

The device for picking up the current from the central rail is also shown in fig. 480. It consists of a kind of inverted vice bolted to an arm, H H, projecting from the frame of the locomotive. The jaws N N of the vice are each perforated with three holes directed obliquely downward and inward, through which bundles of phosphor-bronze wire pass, being fastened by a screw, O. A spiral spring, S, extending between the arms of the vice serves to bring the two brushes M M into close contact with the central rail P, whether the locomotive is moving forward or backward.

The means for regulating the speed of the engine is similar to that employed on the electric railway at the Paris Exposition. By the motion of a lever, fig. 481, the resistance of a suitable rheostat is thrown in or out of the main circuit, thus controlling the amount of current flowing therein. The lever is placed horizontally and moves over contact segments disposed in a circle. These segments are insulated from each other, but are connected by coils of iron wires of different resistances. When the lever is in the position shown in the figures, there is no resistance included in the circuit. When it is moved forward to the next segment, the resistance is 1 ohm. On moving to the next the resist-

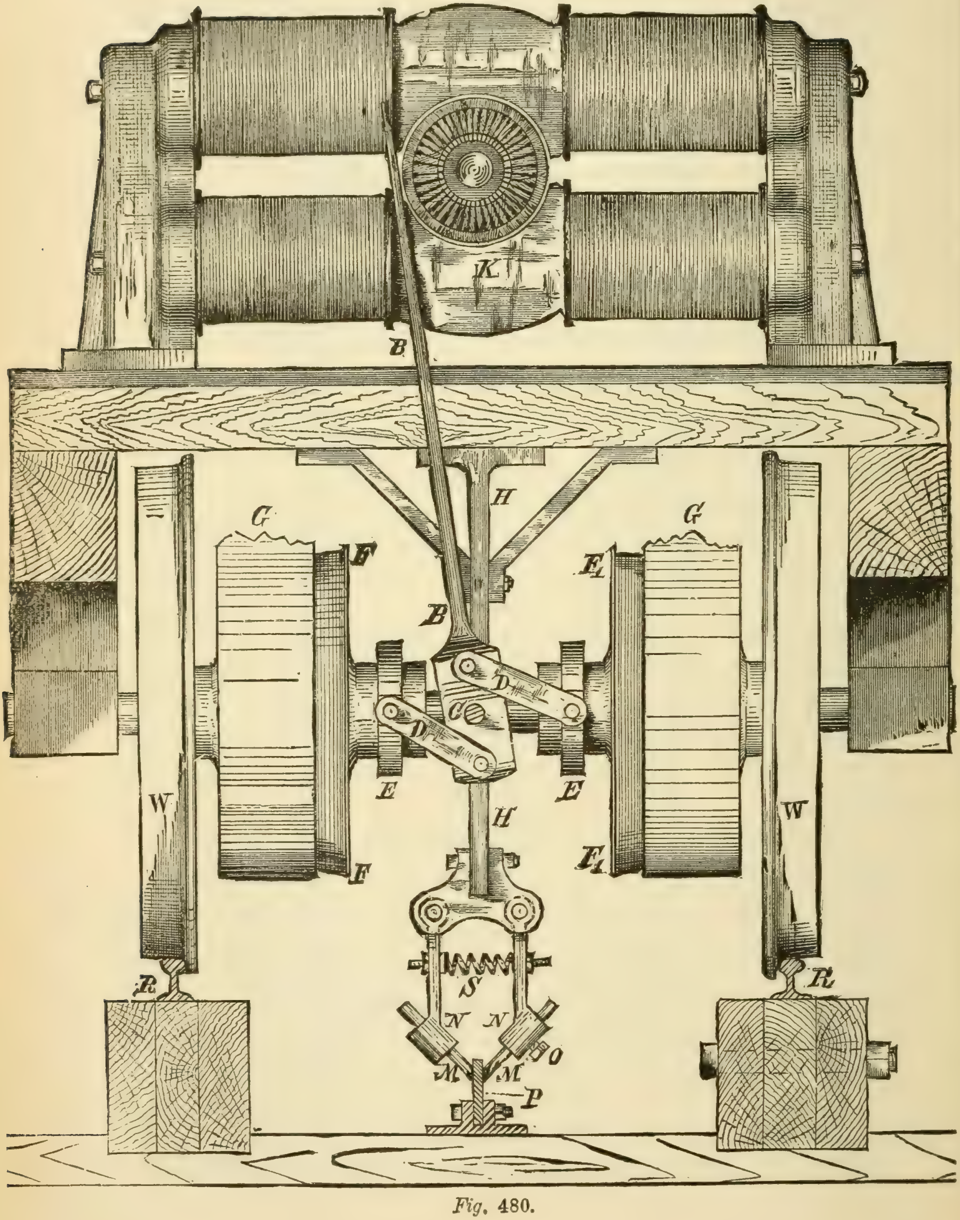


Fig. 480.

ance is 2 ohms, and so on, the amount of resistance included in circuit when the lever touches each segment being in fig. 481 indicated by the figures thereon. The rheostat included two Edison B lamps of 85 ohms each, so that the total resistance when the lever touched the last segment was 174 ohms.

The high resistance necessary at starting to cause the magnetic field of the generator to magnetize itself was readily afforded by this rheostat on closing the circuit. The device for reversing the current at the motor when it is desired to make the locomotive move backward is shown in fig. 482. The lever J causes the wheel H H to turn on the armature shaft G. This wheel gears with two wheels E F, to which are fastened arms C C D D. These arms carry brush-holders and brushes A_1 A_2 B_1 B_2. The function of the device is simply to change the relative direction of the current through the armature of the motor. In the position shown in the figure the positive brush B_2 touches the commutator at the left hand side, while the negative brush A_2 touches it at the right hand side. On moving the lever J as far as R the brushes A_2 B_2 leave contact. On moving the lever still further the brushes A B now come in contact with the commutator of the motor, so that the positive brush B_1 touches the right hand side of the commutator and the negative brush A the left hand side, instead of the opposite.

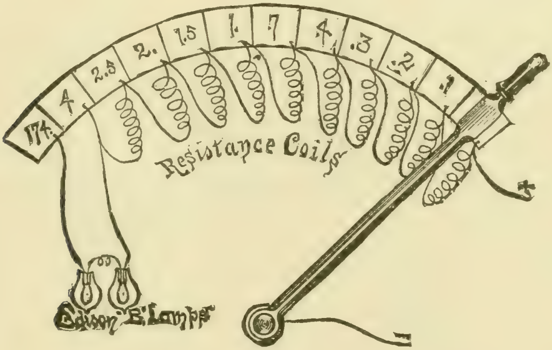


Fig. 481.

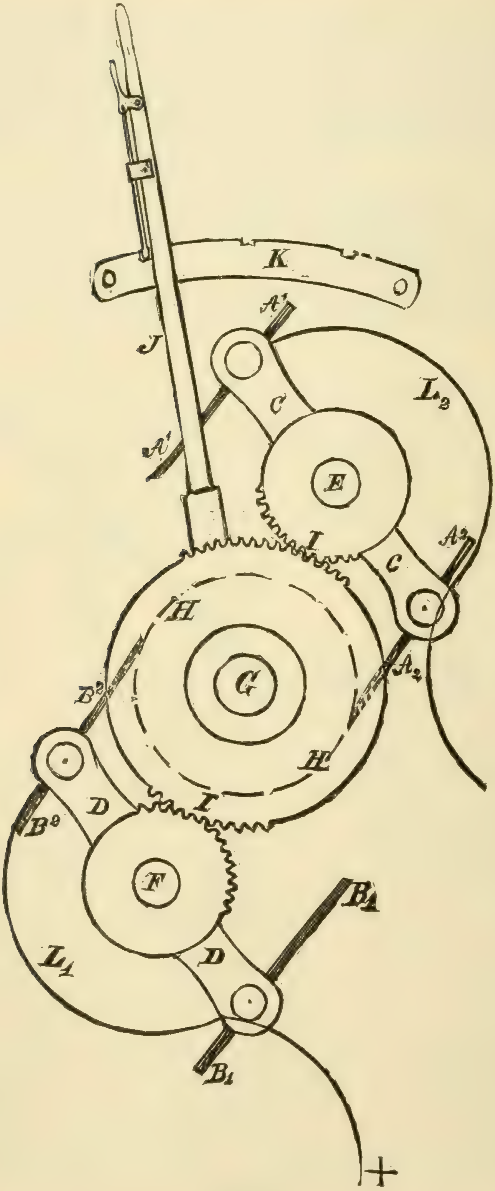


Fig. 482.

The locomotive was provided with an electric bell having a resistance of 350 ohms, which was placed in parallel circuit with the motor; its high resistance preventing any appreciable division of the current from the motor.

The Chicago electric railway, which was the first constructed in this country for business purposes, was opened June 9, and closed June 23, having run in 118 hours 446 miles, and carried 26,805 passengers.

ELECTRIC RAILWAY OPERATED BY ACCUMULATORS.

An electric railway operated by accumulators has been established at the linen bleaching works of Mr. Fourriet, situated at Le Breuil-en-Auge, in the Department of Calvados, France. At this establishment, the fabrics are treated with chlorine and alkaline solutions, by exposure to the sun in the open air in large fields, over which the pieces of linen are spread. Each piece of goods is 100 yards in length; and there are 37 acres of ground which may thus be covered. The track of the railway passes in front of all the lines of goods, over an extent of about 2,500 yards, 550 yards of it being straight, and there being twenty-one branches. The track is a narrow gauge, 2 feet 8 inches, and the rails are of the Vignole type.

The train, which is moved by an electro dynamic motor, fig. 483, actuated by Faure accumulators, fig. 484, leaves the works with empty cars. Having arrived on the ground, it stops, and the motor is made to actuate pick-up rollers, between which is fastened the end of the piece to be gathered in. The cloth, as it leaves the rollers, passes over a reel and is deposited in the car by a workman (fig. 485). As all the pieces spread out on the grass have previously been connected, end to end, one man can take up 5,500 yards in 30 minutes, although by ordinary methods this would take 11 hours.

The electro dynamic motor (fig. 483) consists of a reversible Siemens machine of 20 horse-power. A diminution of speed in the ratio of 1 to 9 is obtained by an endless chain transmission. The machine is controlled by a manœuvring lever shown in fig.

483. In the vertical position the brake is unlocked, and no electrical action takes place. On depressing the lever an electric contact is set up, the resistance of the rheostat decreases and the speed is increased. The speed of the train then varies according as the lever is pushed in one direction or the other. When it is in this position of rest it locks the brake at the same time. There is a second lever, which is arranged for reversing the direction, by acting upon the brushes of the electro dynamic motor; and

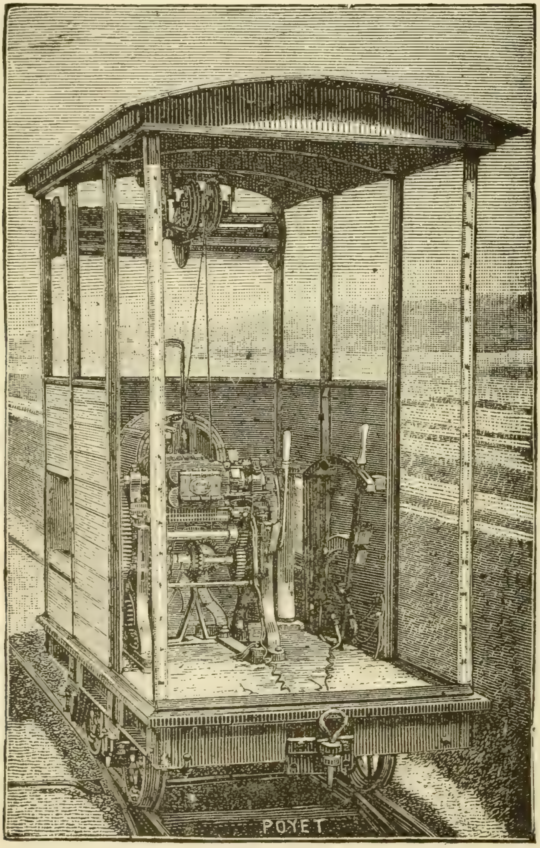


Fig. 483.

a third, which permits of connecting the motor either with the motive axle to move the train or with the rollers to gather up the goods.

The tender (fig. 484) contains the Faure accumulators. These

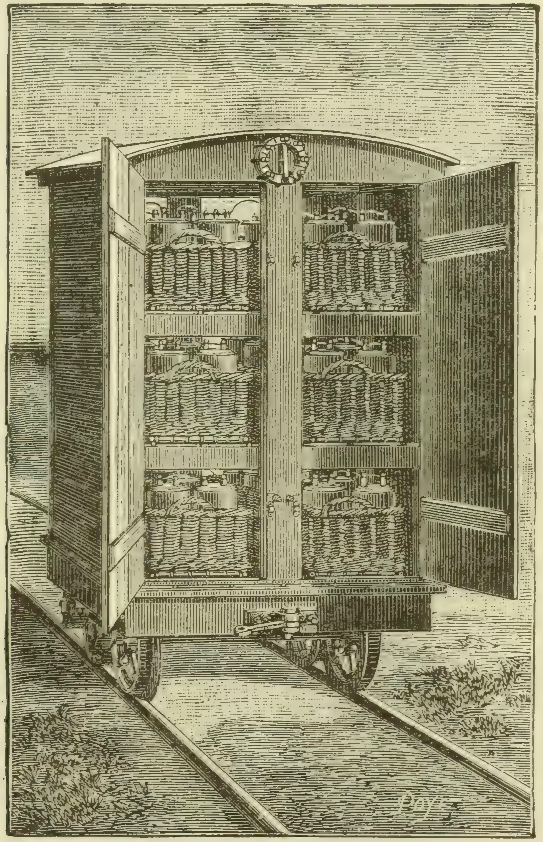


Fig. 484.

are arranged in three tiers in baskets, each containing six of the apparatus. Two of the tiers contain four baskets, and the other contains two. The sixty accumulators weigh 1,100 pounds. These accumulators are charged by a current from the Gramme

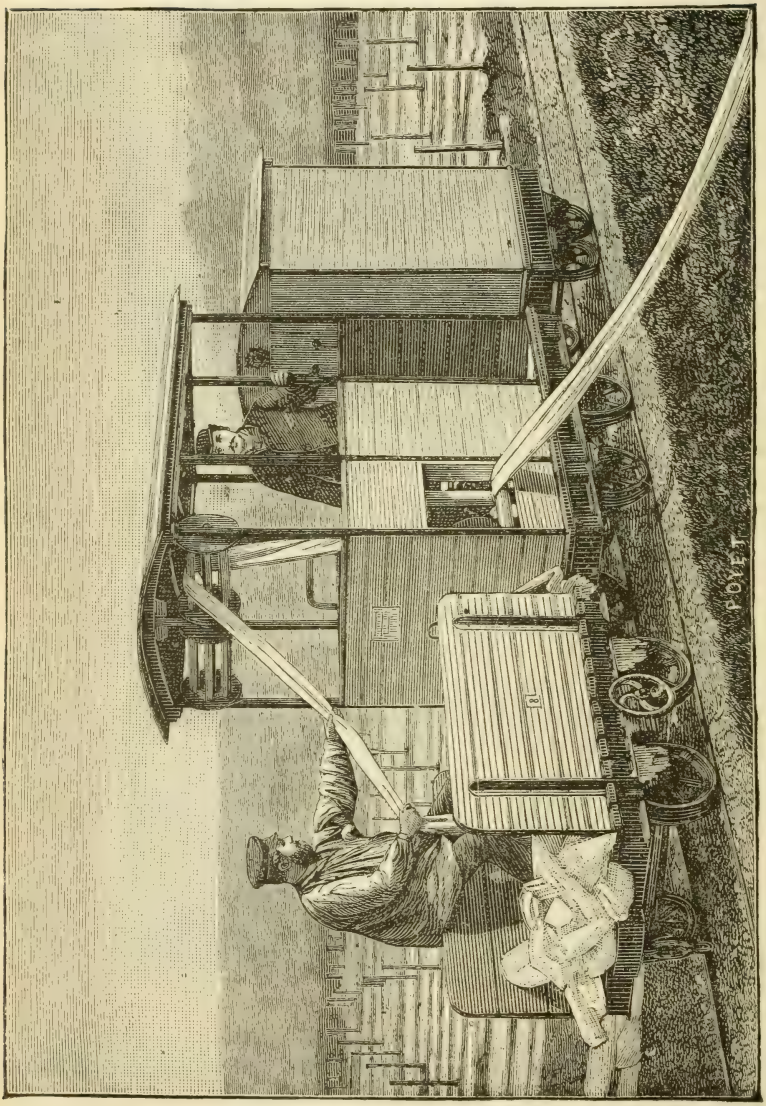


Fig. 485.

machine, which has been used for lighting the work since 1879, by means of eleven Reynier lamps. The weight of the electric engine is 2,000 pounds; that of the tender is 1,500; and each car, when loaded, 1,700. With the workmen and six passengers, the total weight of the train is 14,000 pounds. The accumulators are charged by a current from a Gramme machine, which has been used for lighting the works since 1879, by means of eleven Reynier lamps. The works are capable of producing 60 horse power. Of this only three are utilized during the time of charging, which lasts from five to eight hours. At the upper end of the tender there is a commutator, fig. 484, which admits of setting the accumulators successively in operation—first, to the minimum number of twenty-four, and then by a successive increase of six up to sixty. The speed of the train is eight miles per hour; but in this special application rapidity has in nowise been sought. The duration of working is three hours, and this is limited by the charge of the conductors. If such a system were employed for carrying passengers on tramways, all that part of the apparatus which serves for gathering up the goods would give place to accumulators, thus permitting of the tender being dispensed with.

ELECTRIC RAILWAYS FOR TRANSPORTING DESPATCHES.

To the question of electric railways, properly speaking, is connected that of electric railways designed for the transportation of despatches. This question has already been thoroughly discussed in Paris, where the idea of replacing the pneumatic tubes by a small vehicle impelled electrically was urged in 1879 by Mr. Charles Bontemps, and subsequently renewed in a conference with Dr. Werner Siemens in 1880. The value of this method was subsequently shown by experiment during the same year by Mr. Marcel Deprez, upon a small circular railway constructed in the court of the general telegraph office in Paris, by the aid of his small electric locomotive. In March, 1881, experiments of the same value were made in Vienna with equal success, by the Director General of Telegraphy, Mr. Brunner de

Wattenvyl. In spite of these encouraging results, however, the project which had been formed, following the experiment of Mr. Deprez, to establish an electric post in the sewers of Paris, seems to have been completely abandoned.

At the electrical exhibition at the Palais de l'Industrie, in 1881, this system of transporting despatches was represented by the small locomotive of Mr. Deprez and by the analogous apparatus of Mr. Siemens, shown in fig. 486. The latter consisted of a small dynamo electric machine, mounted upon a small car, to the wheels of which it communicated a movement of rotation. The current was transmitted to the locomotive through the rails and wheels, and to the locomotive was attached a metallic box, mounted upon wheels, in which were placed the despatches.

Mr. Bontemps has fully shown the economy which would result from the replacement of the pneumatic tubes by the electric post, and has demonstrated that if at any given moment forty electric vehicles, each weighing with its despatches thirty-three pounds, were travelling at a speed of twenty feet a second (about fourteen miles an hour), the total work required for the transportation of the despatches upon all the subterranean systems of Paris would be only twelve horse power, while by the pneumatic tubes this work requires one hundred and twenty horse power. With the pneumatic tubes it is necessary to move not only the box containing the despatches, but in addition a considerable column of air, which causes a very much greater friction than that of the box itself. By the pneumatic tube system a very great force is expended in order to be able to transport a relatively limited number of despatches. By the electric post, with an expenditure of force much less, the number of despatches transported would be much greater. The capacity of the vehicle at the same time would not limit its application to the transportation of despatches, as it would be very easy to make it serve for the transportation of letters and newspapers also, which would prove an important auxiliary to the postal service where the telegraph and postal systems were united.

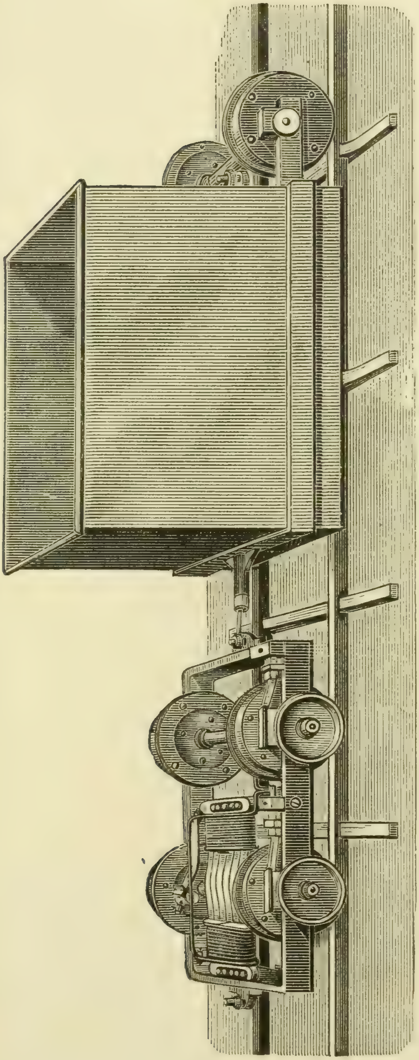


Fig. 486.

PLOUGHING BY ELECTRICITY.

The transmission of power by means of electricity and its application to various industries is constantly increasing. Among those who have devoted much attention to this branch of electrical service are Messrs. Chretien and Felix, two French engineers, who have begun a series of applications which promise to produce important results. In 1879 these gentlemen used a combination for unloading beet boats and loading wagons at the sugar works of Sermaize, in Marne. A Gramme machine was made to turn, by means of a belt, a large wheel, which carried an endless chain of buckets, similar to that used on dredges. The chain ran down into the boat, where six workmen loaded the buckets with the beets that were to be hoisted. The chain worked continuously, and the buckets, as fast as they reached the proper point, dumped the beets automatically into an inclined hopper, through which they were carried to the wagons in waiting. During the season there were unloaded in this way four hundred tons of beets, which had been brought to the port of Sermaize by boats on the canal from the Marne to the Rhine. The governing Gramme machine was situated in the Sermaize sugar works, at a distance of about 325 feet from the port, the two machines being connected by wires carried on posts. The use of this apparatus was found to effect a saving of about 40 per cent. over manual labor.

These gentlemen have since gone still farther by exhibiting (also at Sermaize) a device for ploughing by electricity.

A governing Gramme machine occupies a fixed position in the sugar works, and is actuated by a steam engine. The electricity thereby developed is led by conducting wires, first to one windlass and then to another. These two windlasses, mounted on four-wheeled carriages, are seen at the right and the left of the field in fig. 487. By means of a small steel cable, half an inch in diameter, these windlasses alternately draw back and forth over the field a balance plough provided with four shares, two working in each direction. Motion is given to the windlasses by two Gramme machines, placed at the right and left, as

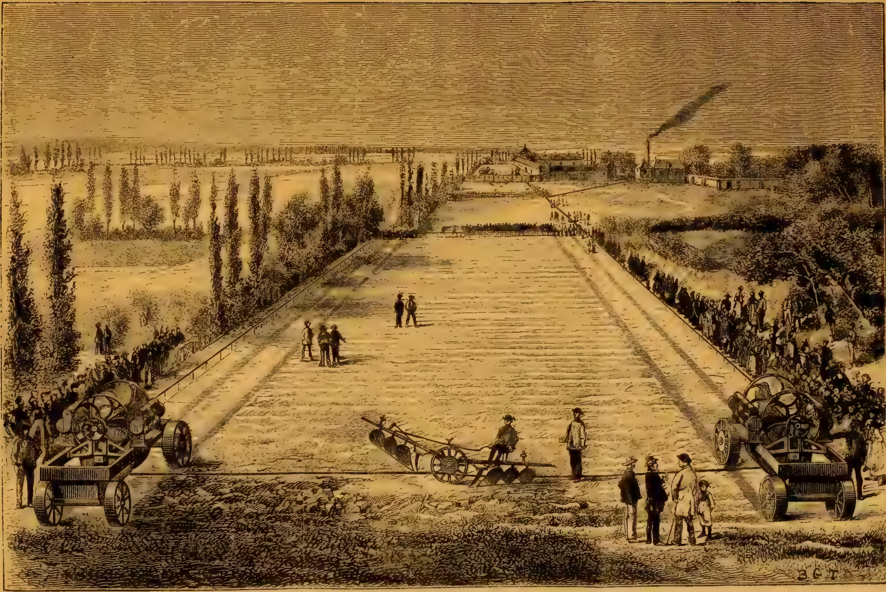


Fig. 487.

bevel wheel carries a pitch pinion, and over this and a cog wheel on the hind axle of the wagon runs a pitch chain. By a simple shifting of the gearing, motion is transferred from the windlass to the latter system and a headland movement of the wagon obtained. The steering of the wagon is effected by a hand wheel in front.

It is urged in favor of this apparatus that it will provide in France the means of supplanting much hand labor, which is scarce, expensive, and not always to be depended upon; and that by its means much water power, now neglected, may be turned to profitable advantage in actuating the machines for producing and transmitting the electricity.

CHAPTER IX.

THE ELECTRICAL STORAGE OF POWER.

The storage of electricity by means of electric accumulators, which has recently played so important a part in the transmission of electric energy, is not an entirely new conception. The hydrogen gas battery suggested by Sir William Grove, in 1841, realized in the most perfect manner the conception of storage, although the power obtained from it was exceedingly slight. This battery was made as follows: Into the two outer necks of a three necked bottle two glass tubes were fitted, each of which was open below, and a platinum wire entered them hermetically above, to which a long strip of platinum was soldered, extending nearly to the bottom of the tube. Little cups, containing mercury, were attached to the upper end of these wires. The bottle was filled with slightly acidulated water, and the poles of a galvanic battery were placed in the little cups. Water was thereby decomposed; oxygen forming in one tube and hydrogen in the other. When the battery wires were removed, no change took place till metallic connection was established between the cups, when oxygen and hydrogen gradually disappeared, attended by an electric current, which passed from the oxygen to the hydrogen. When several of these were put together in a battery, the connection being always oxygen to hydrogen, they could decompose water. The most important fact illustrated by this battery was that the oxygen and hydrogen, liberated by galvanic agency, when left to themselves, produced a current the opposite to that which separated them. When the poles of the decomposing battery were in the mercury cups, hydrogen was given off at the —, and oxygen at the + pole; and as opposite electricities attract, it is manifest that the hydrogen in this action was +, and the oxygen —. When two gases formed by means of the platinum plates, a galvanic pair by themselves, the current proceeded from the + to the — within the liquid, and the reverse way between the poles, which was the opposite of the direction of the original current. It is manifest, therefore, that where oxygen or hydrogen is set free at any point in a galvanic circuit, they will tend to send a counter current. This tendency is called galvanic polarization.

Sir William Siemens, in 1858, constructed a battery of considerable power by substituting porous carbon or platinum, impregnating the same with a precipitate of lead peroxidized by a charging current. At that time, however, little practical importance was attached to the subject, and even when Planté, in 1860, produced his secondary battery, composed of lead plates peroxidized by a charging current, little more than scientific curiosity was excited. It is only since the electro dynamic motor has become an accomplished fact that the importance of this mode of storing energy has become of practical importance, and great credit is due to Faure, Kabath, Volckman and others for putting this valuable addition to practical science into available form.

Fig. 488 shows a single pile of Faure battery operating a small electric motor. Fig. 489 shows the method of combining the plates. Fig. 490 shows a battery arranged with a commutator for combining the elements for tension or quantity. The plates are of pure lead foil, having a width of 7 inches, a height of 7⅛ inches, with an ear projecting from the top 1½ inches wide and 3 inches high. The total effective surface on both sides and edges of each plate is 100 square inches. These secondary elements were constructed as follows:

After cutting out a sufficient number of lead plates, pieces of Canton flannel, 15 inches long and 7½ inches wide, were cut, together with as many sheets of blotting paper, 7½ inches square, as there were lead plates. A thick paint of red lead was then prepared by mixing the dry pigment with water containing one tenth of sulphuric acid. This paint had a consistency of paste, and was applied thickly to one side of the sheet of lead. The Canton flannel having been painted to within one quarter inch of its edges on the nap side, the lead was laid, painted side down, upon the painted Canton flannel, when the other side of the lead was painted and the cloth was folded over the lead,

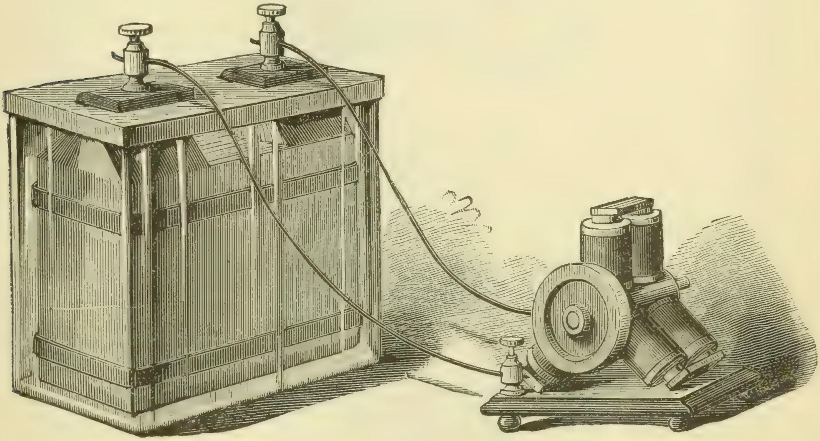


Fig. 488.

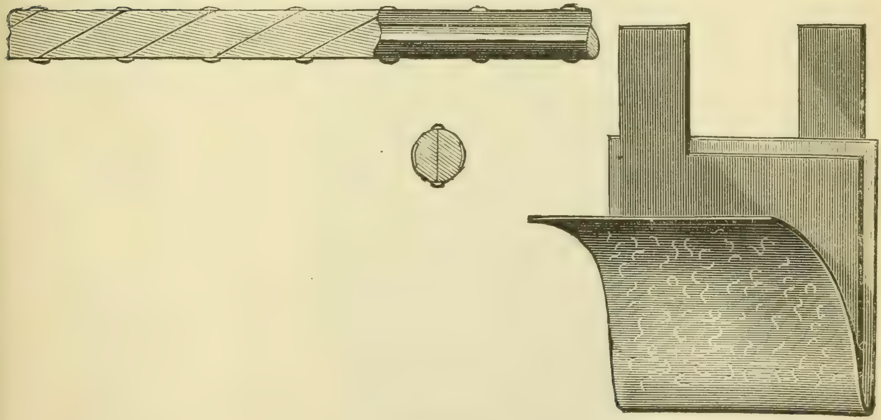
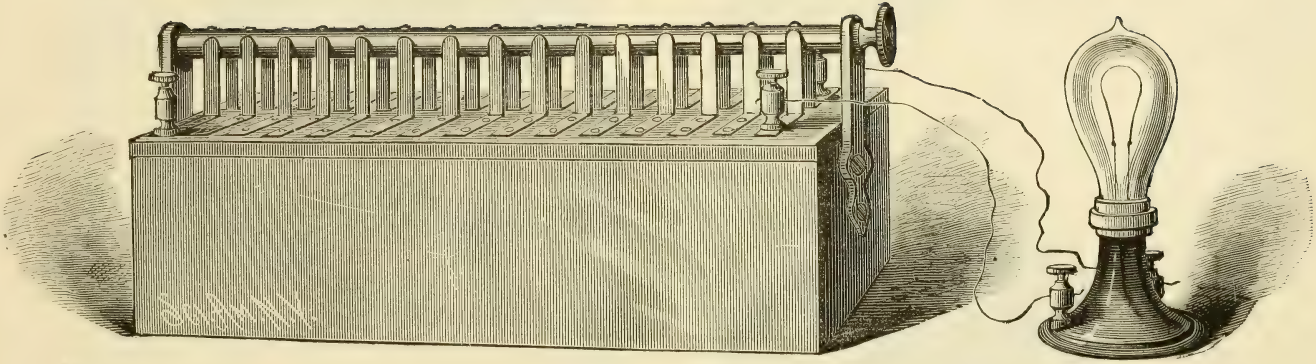


Fig. 489.

completely enveloping it, with the exception of the ear at the top, and projecting about one quarter inch beyond the edges of



Fig, 490.

the lead. The lead with its envelope was then laid upon a level board, and another plate was prepared in the same manner and placed over the first, with an intervening layer of blotting paper, and with the ear placed opposite the ear of the first. Other lead plates were added in the same way, with the interposed sheet of blotting paper and with the ears alternating in position, as indicated in fig. 489. When ten plates had been placed together in this manner they were clamped together, and the ears were passed through a slit in the wooden cover of the containing cell and bent down upon the top of the cover, as shown in fig. 488. They were then pierced and traversed by the screw of a binding post which enters the wood. In this way each pole of the element was furnished with a binding post, and at the same time firmly secured to the cover. The cell was then filled with acidulated water—water 10 parts, sulphuric acid 1 part—and after the cloth and blotting paper had become saturated the element was connected with a dynamo electric machine. One element of ten plates, after receiving the current from the dynamo for ten minutes, operated the small motor, shown in fig. 488, three hours, and another ten minutes' application of the current from the dynamo charged it so that after eighteen hours of rest it yielded a current which was apparently as strong as when it was first charged on the previous day; but a time test proved that it was incapable of running the motor for quite so long a time as when the current is used soon after storing.

KABATH'S ACCUMULATOR.

The principal element of the Kabath accumulator is shown in fig. 491, and consists of two series of lead ribbons, about $\frac{1}{200}$ inch thick and $\frac{1}{2}$ inch wide; one series being 14 inches, and the other 20 inches long. The latter are passed between two grooved cylinders, where they are rolled and corrugated in such a way that their length is reduced to that of the first series. A flat and corrugated ribbon are then superposed alternately, until a group of 190 bands has been put together, having a total width of 3½ inches. This assemblage is then enclosed in an envelope of sheet lead, soldered together at the edges so as to form a sheath. The two faces of this envelope are pierced with round holes ½ inch in diameter, distributed in several parallel rows, and ranged in groups as shown in the figure. These openings allow the liquid, in which the sections are immersed, to circulate freely. At the ends, the two lips of the envelopes are brought together and soldered. At one end a strip of lead slightly bent is added to serve as a rheophore. This constitutes a single cell of the Kabath accumulator which, when finished, presents the appearance of a plate 15 inches long, 3½ inches wide, and ½ inch thick, the weight being about 2.2 lb. The strips of lead are set close together, as shown at the left hand of fig. 492, but in such a way that the corrugations of the gauffered ribbons are not in the least flattened. On looking through the circular openings in the envelope, light can be seen between the flat and serrated strips.

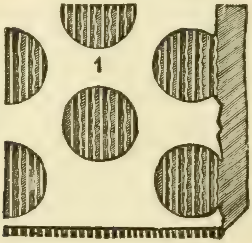


Fig. 491.

Originally these cells were made in two types of portable and vertical accumulators. One of these, the laboratory type, fig. 493, is formed of six cells placed in a glass chamber, the whole weighing 13 lbs.; the other, the industrial type, is shown in fig. 492, which indicate the collection of elements and the box enclosing them. This type is made up of twelve cells and weighs 84 lbs. Mr. de Kabath has recently given up these forms in favor of an open trough type, which are contained in rectangular wooden boxes, lined inside with hard rubber, separated from the wood by a thin coat of insulating mastic formed of arkanson and paraffine. The cells are placed edgewise, as shown in figs. 494 and 495, parallel to each other, their flattened ends passing between vertical strips of ebonite, which act as guides.

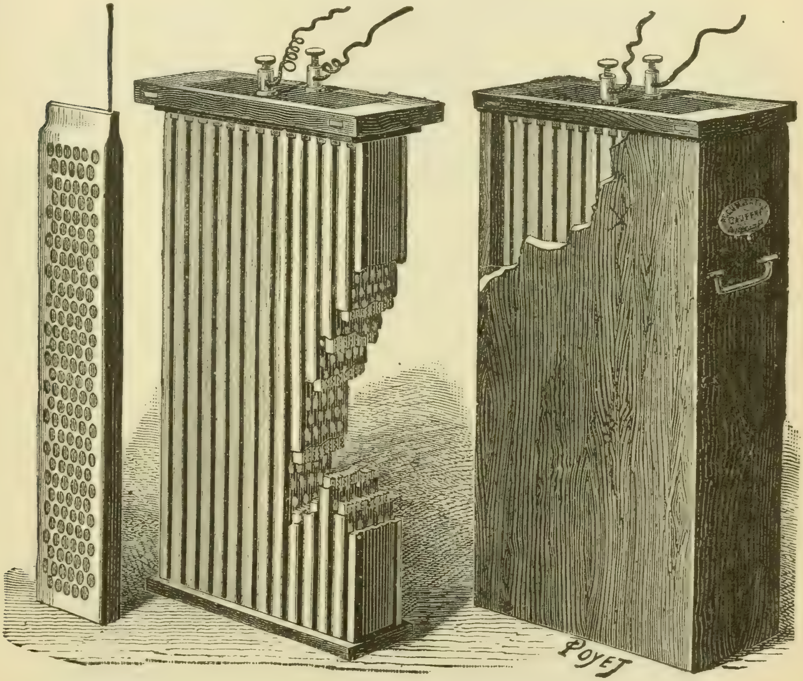


Fig. 492.

This latter detail is advantageously replaced by glass plates, having the same height as the box, and provided with two grooves. These plates are placed at opposite ends of the box, and receive two cells, forming a couple. Fig. 495 shows such a couple between the two glass guides, the box of course not being indicated. The lead rheophores are alternated, and are soldered to the envelope of the cells. With a metal of higher conductivity, copper for example, bathed in the surrounding liquid, a destructive hydro electric action would be set up. The ends of the lead rheophores are above the top of the trough, and are united by screwed collars, seen in fig. 494, one of which is shown

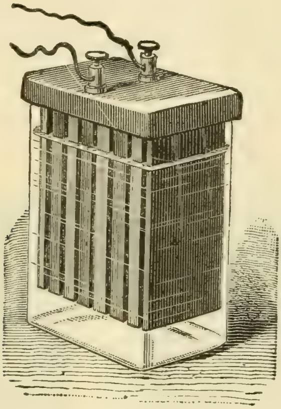


Fig. 493.

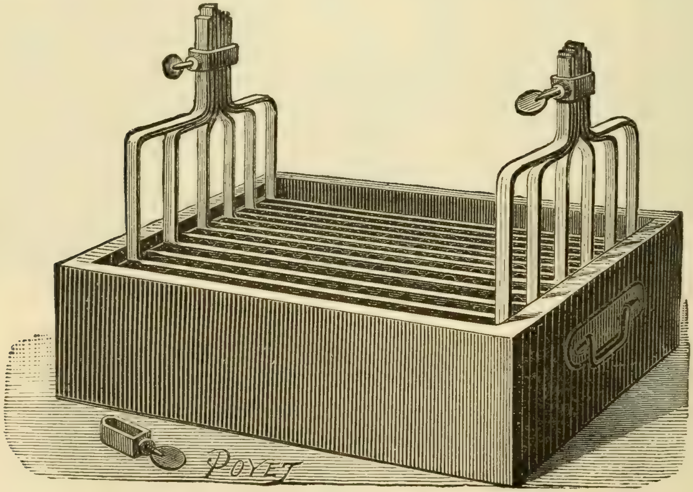


Fig. 494.

separately on the side of the box. This collar also receives the conducting wire. To avoid any direct pressure of the screw on the lead strips which would throw them out of shape, a small copper packing piece is introduced, on which the end of the compressing screw bears. The enclosing troughs are furnished with handles (fig. 496) for convenience of transport. Two types of this new arrangement are in use—a small pattern corresponding to the vertical laboratory type described above, and a large size corresponding to the industrial model. A third and larger type is now being made. The two former are of the following character:

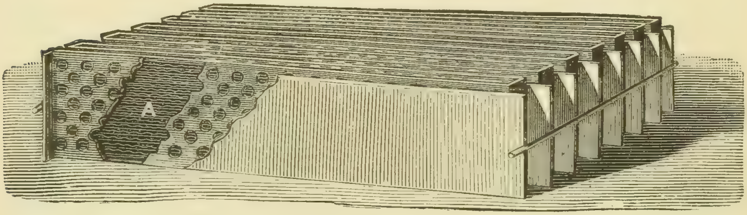


Fig. 495.

	Weight.	Electro motive Force.	Resistance.	Price.
	Lb.	Volts.	Ohm.	Dollars.
Laboratory type..............	13.2	2.2	0.05	6.00
Industrial type...............	55	2.2	0.05	15.00

From these data it will be seen that the intensity of the current furnished by the accumulator with a closed circuit should be, according to Ohm's law, $\frac{2.2}{0.05} = 44$ ampères; but it is evident that this is a maximum that cannot be attained in doing useful work, since it assumes the absence of exterior resistance. It is known that the maximum useful effect is obtained when the external and internal circuits have the same resistance. In this case the intensity of the current would be $\frac{2.2}{2 \times 0.05} = 22$ ampères. A rate of 15 to 17 ampères may therefore be adopted for average work.

This description of the Kabath accumulators will show how easily they may be transported or modified, when one or several cells require to be replaced. They have only to be emptied and the rheophores detached; each cell can then be lifted from the guides, and handled independent of the adjoining cell. It will be seen, moreover, when speaking of the formation of these accumulators, that facility of handling is not the only advantage. All secondary batteries derived from the Planté type differ from each other only in the details of their construction. The principle is the same, and also the manner in which the electro motive force is produced, since the latter depends solely on the same chemical action.

In making an accumulator, after the parts have been put together, the next process is to form it, that is, to produce the deposit of oxide of lead, which gives the polarizing quality to the battery, and enables it to furnish a secondary current. In the Kabath and Planté batteries this is done by the electric current alone. To form a battery, a glass or stoneware vessel is filled with distilled water, to which one tenth of sulphuric acid, quite free from iron and arsenic, is added. When cold, this mixture is poured into the troughs containing the battery, to within a small distance of the edge, thus submerging the cells.

Formation is effected slowly, and in such a way that the oxide may adhere as firmly as possible. The process is kept up for several days, the direction of the current kept flowing through the battery being sometimes reversed, and the battery also being allowed to discharge. In this manner the lead strips are thoroughly attacked, the oxidation penetrating to the centre of their thickness. Despite this relatively great oxidation, the thin strips of lead are not readily injured by long use, and a cell can be easily removed and replaced. There are no means of knowing with exactitude at what moment the battery is completely formed. Theoretically, the process should be complete when the whole mass of lead plate has been equally attacked. Practically, it is finished when the chemical action has been carried so far that the solidity and cohesion of the lead ribbons are within narrow limits of being compromised. Charging an accumulator is only a repetition of a part of the forming process, since it is effected in the same way, and reproduces the effect of the preceding phase.

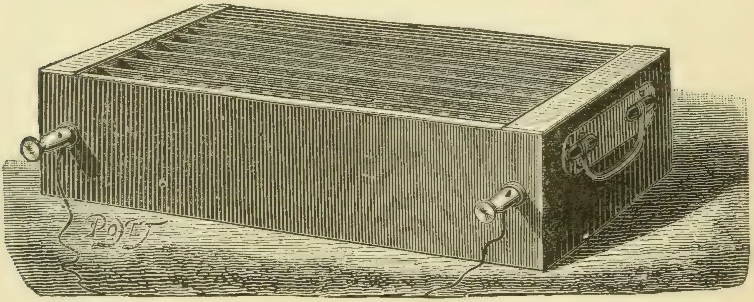


Fig. 496.

All sources of direct currents are suitable for charging secondary batteries; it is only necessary that they should be constant and economical and have sufficient electro motive force. But dynamo electric generators with separate excitators are the best for the purpose, because the direction of their current varies only with that of rotation, which is a favorable condition to avoid changing the poles during charging. Generally, however, self-exciting dynamo machines are used, such as the workshop type of the Gramme generator. These machines are employed at Kabath's factory. Each generator is driven at a speed of 800 revolutions per minute, and produces sufficient current to charge thirty accumulators, arranged in three series of ten each. This arrangement requires very attentive watching, because if any accident occurred to reduce the electro motive force of the generator, the current might be reversed, and the accumulators would discharge into the generator, resulting in a loss of work, heating, and the danger of burning the conductors. To avoid the evils of such an accident, Kabath has devised an automatic breaker, to open the circuit whenever the generator current falls below a certain electro motive force.

A question of great interest in connection with the electric accumulator is that of its permanence. A fear has been expressed by many that local action would soon destroy the fabric of which it is composed, and that the active surfaces would become coated with sulphate of lead, preventing further action. It has, however, lately been proved by scientific investigation that the action of the secondary battery depends essentially upon the alternative composition and decomposition of sulphate of lead, which is therefore not an enemy of, but the best friend to, its continued action. The action of the battery depends simply upon the decomposition of the coating of sulphate of lead, so that, commencing with sulphate of lead on both surfaces, this is on the one hand changed into metallic lead, and on the other hand into peroxide; by the action of the battery in producing power it is changed back into its original condition; and there is no *a priori* reason why such a battery should not be available for use for a very long time. Of course it cannot be expected that as much effective power can be got out of it as is put in. Precisely what the loss is, those who are in the best position to know are not prepared to say, but certainly it is not of such serious import as to prevent the practical use of these secondary batteries for many useful purposes.

CHAPTER X.

ELECTRICAL MEASUREMENT.

An essential step in the direction of learning any branch of physical science is to find principles of numerical reckoning, and methods for practically measuring some quality connected therewith. The first step toward numerical reckoning of properties of matter, is the discovery of a continuously varying action of some kind, and the means of definitely observing it and measuring it in terms of some arbitrary unit or scale division. But to complete the science of measurement in any department, and especially in that of electricity, it is necessary to fix on something absolutely definite as the unit of reckoning.

UNITS OF MEASUREMENT.

Cavendish and Coulomb, in the last century, furnished the requisite foundation for a complete system of electric and magnetic measurement; but the first complete method of scientific measurement was that of Gauss, in his system of absolute measurement for terrestrial magnetism, which gave the starting impulse for the whole system of absolute measurement as it exists to-day throughout the range of electric science.

Gauss' principle of absolute measurement for electricity and magnetism, is merely an extension of the astronomers' method of reckoning mass in terms of the universal gravitation unit of matter; and of the reckoning of force adopted by astronomers, in common with all workers in mathematical dynamics, according to which the unit of force is that force which, acting on a unit of mass for a unit of time, generates a velocity equal to the unit of velocity. It leaves the units of mass, space and time to be assumed arbitrarily.

As early as 1851, Sir William Thomson began using the absolute system in the reckoning of electro motive forces of voltaic cells, and the electric resistance of conductors, in electro magnetic units; and after advocating the general use of the absolute system for ten years, obtained the appointment of a committee of the British Association on electrical standards, which, in 1869, launched the absolute system for general use, with arrangements for the supply of standards for resistance coils in terms of a unit, first called the British Association unit, and afterward the ohm; of which the resistance reckoned in electro magnetic measure was to be, as nearly as possible, ten thousand kilometres per second. In 1861, Sir Charles Bright and Latimer Clark communicated a paper to the British Association, in which the names that are now in use—ohms, volts, farads and micro-farads—were suggested, together with a complete continuous system of measurement, which, while it did not fulfil all the conditions of the absolute system, fulfilled some of them in an exceedingly useful manner for practical purposes. Since 1871, the absolute system has been in general use in the United States and Great Britain, but it was ten years later before its definitive practical adoption by France, Germany and the other continental countries of Europe in conformity with the decree of the international conference for the determination of electric units, held at Paris in October, 1881. The decision adopted was, not to take the British Association unit, whose accuracy was the subject of well founded doubt, but that as soon as good evidence is given of a sufficiently near measurement for practical purposes of the resistance of any conductor, then the unit which the British Association had aimed at would be adopted; but it was to be left to the judgment and convenience of the users of standards when to make the change, should a change be necessary, from the British Association unit—the ohm—or from the Siemens unit—the resistance of a column of mercury at zero temperature, a metre in length and a square millimetre in section—in order to bring the measurement into more close agreement with the absolute reckoning.

FUNDAMENTAL UNITS.

For mechanical and electrical measurements, the centimetre, the gramme and the second have been adopted as the fundamental units of length (L), mass (M), and time (T), respectively; whence they, and the units derived from them, are called for brevity the C. G. S. system of absolute units. The intimate relation which exists between the centimetre and the gramme—the latter being the weight of a cubic centimetre of distilled water at the temperature of its maximum density, viz., 4° Centigrade—is a peculiar advantage of these units.

DERIVED UNITS.

To quantities of different kinds separate units are respectively assigned. The numerical value of any concrete quantity is the ratio it bears to the unit of its kind. A unit of one kind of quantity is sometimes defined by reference to a unit of another kind of quantity, and still more frequently by reference to two or more units of other kinds. The units thus defined are called derived units, and the practical advantage of employing such units is, that they are more convenient for calculation than independent units would be, because they avoid the introduction of additional factors, which would involve needless labor in calculating and difficulty in remembering. The derived mechanical and electro magnetic units are the only ones we shall have occasion to describe here.

DERIVED MECHANICAL UNITS.

The C. G. S. unit of velocity (V) is the velocity of a body which passes over a centimetre in a second, and in fundamental units it is, therefore, equal to

$$\frac{L}{T}$$

Momentum or quantity of motion of a body is defined as the product of its mass into its velocity, hence its value is

$$M \times \frac{L}{T} = \frac{ML}{T}.$$

The unit of force (F) is that force which, acting on a gramme of matter for a second, generates a velocity of one centimetre a second. This unit is named the dyne. Since a force is measured by the momentum which it generates per unit of time, and is therefore the quotient of momentum divided by time, the value of the dyne in fundamental units is

$$\frac{ML}{T} \div T = \frac{ML}{T^2}.$$

Work is the product of the intensity of the force by the distance through which it operates. The unit of work is called the erg. It is the work done by a dyne in passing through the distance of a centimetre. Being the product of force and distance, it is equal to

$$\frac{ML}{T^2} \times L = \frac{ML^2}{T^2}.$$

The C. G. S. unit of energy is also the erg, energy being measured by the amount of work done.

PRACTICAL MECHANICAL UNITS.

The C. G. S. unit of power is that power which does work at the rate of one erg per second. For practical work this unit is too small, as it necessitates the use of inconveniently large numbers. The kilogrammetre, for example, is equal to 98,000,000 ergs, and the gramme-centimetre is equal to 980 ergs. A second unit, equal to one million ergs, is therefore employed. This unit is called the meg-erg.

The horse power is still generally employed as the practical unit of work, although it does not harmonize with the C. G. S. system. It is equal to 33,000 foot pounds per minute, or 550 foot pounds per second; the foot pound being equal to one pound raised to a height of one foot. In C. G. S. units the foot pound is equal to 13,556,000 ergs, and the horse power to 7,455,600,000 ergs. The horse power is equal, also, to 76 kilogrammetres per second.

According to the definition of the dyne it will be seen that taking p as the weight of a gramme, and g the acceleration of gravity, then $\frac{p}{g} = \frac{\text{dyne.}}{1}$. The weight of the gramme is thus equal to g dynes, and as the value of g at any part of the earth's surface is about 980 centimetres per second, it is equal to 980 dynes. To obtain an exact result, the value of g at the station where the calculations are made must, of course, be actually ascertained.

TABLES OF DIMENSIONS AND OTHER CONSTANTS.

Fundamental Units.

Unit of	Symbol.	Name of Unit.
Length	L	Centimetre.
Mass	M	Gramme.
Time	T	Second.

Derived Mechanical Units.

Unit of	Name.	Symbol.	Dimensions of Unit.
Velocity	....	V	$L \div T$
Momentum	....	..	$ML \div T$
Force	Dyne.	F	$ML \div T^2$
Work and energy	Erg.	W	$ML^2 \div T^2$
Power	Erg, per second.	....	$ML^2 \div T$

Practical Mechanical Units.

Name of Unit.	Dimensions of Unit.
Meg-erg	10^6 Ergs.
Gramme-centimetre	980. "
Kilogramme-metre	9.8×10^7 Ergs.
Foot pound	1.3556×10^7 Ergs.
Horse power	7.456×10^9 "

Heat Units.

The heat units based on the C. G. S. system are the degree which measures temperature, and the gramme degree, which is the quantity of heat necessary to raise one gramme of water from zero to one degree centigrade. The latter unit is equal to 4.1624×10^7 ergs.

DERIVED ELECTRO MAGNETIC UNITS.

The electrical units, which are based on purely mechanical measurements, have been determined from the natural relation existing between the various electrical quantities, and between these and the fundamental units. The electrical phenomena susceptible of measurement are four in number, viz. : electro motive force (E); current (C); quantity (Q); and resistance (R). The immediate force producing a current, or, in other words, causing a transfer of electricity, is called electro motive force. Whenever electro motive force exists between two points of a conductor, those points are said to be at different potentials.

A difference of potential cannot exist in a conductor without effecting work or its equivalent; a weight may be raised, the conductor become heated, chemical decomposition effected, or soft iron magnetized. These effects are said to be due to a current of electricity in the conductor, and are proportional to its strength.

The quantity of electricity conveyed by any given current is simply proportional to the strength of the current and to the time (t) during which it flows.

When the electro motive force between two points of a circuit remains constant, the amount of work done is altered by modifying the material and form of the conductor, or, in other words, currents of different magnitudes are produced. The quality of a conductor, in virtue of which it prevents the performance of more than a certain amount of work in a given time by a given electro motive force, is called resistance.

The relations of these phenomena one to another and to force and work were determined experimentally, independently of the present units, and are as follows:

First, by Ohm's law, we have the equation

$$C = \frac{E}{R} \dots\dots\dots\dots (1)$$

From this it follows that the unit electro motive force produces the unit current in a circuit of unit resistance.

Second, by Faraday's proof

$$Q = Ct \dots\dots\dots\dots (2)$$

and from this equation it follows that the unit quantity is the quantity conveyed by unit current in unit time.

Our knowledge of electricity is derived from the mechanical, chemical and thermal effects which it produces. The connection between electrical magnitudes and mechanical work was determined by Joule, and, in mathematical language, is as follows:

$$W = C^2 Rt \dots\dots\dots\dots (3)$$

where W equals the work equivalent to all the effects produced in the circuit. From this equation it follows that the unit current flowing for a unit of time through a circuit of unit resistance will perform a unit of work or its equivalent.

The force exerted on the pole of a magnet by a current in its neighborhood is a purely mechanical one. This force (f) is proportional to the magnetic strength (m) of the pole of the magnet, and to the strength of the current; and if the conductor be bent in a circle of the radius (k) round the pole, the force is proportional to the length of the conductor (L); it is also inversely proportional to the square of the distance (k) of the pole from the conductor. Hence we have

$$f = \frac{C\,L\,m}{k^2} \dots\dots\dots\dots (4)$$

From this equation it follows that the unit length of the unit current will produce the unit force at the unit distance.

From these four equations were determined the values of the four electrical units in terms of L, M and T. It will be seen that in the fundamental equation (4), besides the measurement of time, space and mass, a fourth measurement (m) of a magnetic pole is required; but this measurement is itself made in terms of the mechanical units, for the unit pole is simply that which repels another unit pole at unit distance with unit force. Chemical and thermal effects are also measured by the unit of work.

The dimensions of the unit pole are

$$\frac{L^{\frac{3}{2}}\ M^{\frac{1}{2}}}{T} \ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

By substituting this value for (m) in equation (4) the value of (C), the unit current is found to be

$$C = \frac{L^{\frac{1}{2}}\ M^{\frac{1}{2}}}{T} \ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

From equations (1) and (3) we can deduce the relation

$$W = C\ E\ t \ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

whence

$$E = \frac{W}{C\ t} \ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

From equations (6) and (8) and the dimensions of W in fundamental units, the value of E is found to be

$$E = \frac{L^{\frac{3}{2}}\ M^{\frac{1}{2}}}{T^2} \ldots\ldots\ldots\ldots\ldots\ldots \text{(9)}$$

From equation (1)

$$R = \frac{E}{C}$$

The dimensions of (R) are found by comparing those of (E) and (C) to be

$$R = \frac{L}{T} \ldots\ldots\ldots\ldots\ldots\ldots \text{(10)}$$

or those of a simple velocity.

Thus an intimate relation exists between the mechanical and electrical units, which realizes the advantages of derived units to which we have called attention, and furthermore, in one sense, these units are independent of any values that may be assigned to them.

The two units of electro motive force and of resistance, expressed by the C. G. S. system, would have too small a value for ordinary purposes. The unit of electro motive force, therefore, is practically expressed in one hundred millions of C. G. S. units of electro motive force, or 10^8 and the unit of resistance in one thousand millions of C. G. S. units, or 10^9. As the three quantities, electro motive force, resistance, and current, are connected together by the simple law which is expressed as follows,

$$\text{Current} = \frac{\text{Electro motive force}}{\text{Resistance}} = \frac{10^8}{10^9}$$

the practical unit of current is evidently equal to one-tenth of the absolute unit of current or 10^{-1}.

The practical unit of quantity, which is plainly the quantity of electricity given by a practical unit of current in unit time, is equal to one tenth of the C. G. S. unit of quantity or 10^{-1}.

The practical unit of electro motive force is called a volt.
“ “ “ “ resistance “ “ an ohm.
“ “ “ “ current “ “ an ampère.
“ “ “ “ quantity “ “ a coulomb.

The capacity of a condenser which holds one coulomb when charged to a potential of one volt is called a farad (K). The farad is thus the practical unit of capacity and its value is

$$\text{Farad} = \frac{10^{-1}}{10^8} = 10^{-9} \text{ C. G. S. units of capacity.}$$

$$= L^{-1}\ T^{-2} \text{ in fundamental units.}$$

Standard practical units of resistance and of capacity have been constructed. Standards of intensity—strength of current—have not yet been made; but the values may be closely ascertained by graduated apparatus, such as the tangent galvanometer, or the electro-dynamometer. The intensity of a current is also readily measured by the chemical action which it is capable of producing. The intensity of a current is the same at all points of the circuit which it traverses, and the chemical action is proportional to the intensity. The approximate measure of the ampère is the intensity capable of precipitating 4 grammes of silver per hour, or 1.19 grammes of copper, or 1.23 grammes of zinc, or of decomposing ·09378 grammes of water per second. Current and resistance being known, electro motive force is readily calculated.

For defining quantities multiplied or divided by one million, the prefixes mega and micro are used (the meg-erg already described is an example), so that a meg-ohm stands for one million ohms and a micro-farad denotes one millionth part of a farad. Thus the sign 10^6 would represent the prefix mega, and the sign 10^{-6} the prefix micro; or 1.000,000 and ·000001 respectively.

In the practical application of these units the principle of the conservation of energy, which controls all problems in the measurement of force, is an element of great importance. The word energy is applicable to all physical manifestations. Conservation results from the important fact that energy, expended in any form, is always to be found integrally in some other form of work.

Potential, in mechanics, means the power of doing work; the electrical potential of any point in a body, or in space, is defined as the quantity of work done in bringing unit electrification from an infinite distance up to that point. Thus the potential at A may be different from that at B. If A be of higher potential than B, then, on connecting them by a conductor, a current will flow from A to B, and continue until the potentials are equalized. There is an analogy to this in the flow of water through pipes, where the difference of level corresponds to a difference of potential; this difference of level produces a hydrostatic pressure which corresponds to electro motive force; when the tap is turned, the water flows out; that represents the current. Wherever there is a difference of potential, there is electro motive force, and on completing the circuit,—the analogue of opening the tap,—a current will be established.

The terms electro motive force and difference of potential are thus not exactly synonymous, and it is useful to distinguish between them.

No standard of electro motive force has yet been devised: the electro motive force of a Daniell cell, however, is an approximation to the volt. According to Siemens it is 1.106 volts and according to Latimer Clark 1.079 volts. The latter figure is most generally adopted.

At the General Post Office, in London, a standard cell has been adopted, consisting of a Daniell's element, arranged as shown in fig. 497, consisting of three chambers. In the left hand chamber is placed a zinc plate, Z, immersed in water, and in the right hand chamber a flat porous pot, C, containing a copper plate and crystals of sulphate of copper, the pot being kept immersed in water. These two chambers are called idle cells, as the zinc and porous pot are only kept in them when the cell is not in use. The centre chamber contains a semi-saturated solution of sulphate of zinc, and a piece of zinc rod, *z*, the latter lying in a small compartment at the bottom of the chamber. When the cell is required for use, the zinc plate and the porous pot and its contents are removed from their idle cells

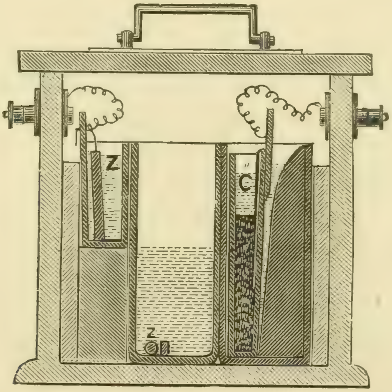


Fig. 497.

and placed in the centre chamber; the cell is then ready for work. When the cell is no longer required for use, the zinc plate and porous pot are again placed in their respective idle chambers, and while the cell is at rest any sulphate of copper solution which may have become mingled with the sulphate of zinc solution in the centre chamber will be decomposed and the copper deposited on the zinc rod, thus keeping the solution always clear.

When in thoroughly good condition (assuming Clark's figure to be correct, as it is most generally taken), the foregoing cell has an electro motive force of 1.079 volts, but if it is in daily use the power is practically a little less than this, so in the post office the value is assumed to be 1.070 as being generally nearer the mark. If care be taken to keep the zinc plate clean, and the sulphate of zinc solution not too nearly saturated, say under 20 deg. Baume, 1.079 may be taken as correct.

A cell whose electro motive force is even more constant than that of the Daniell is extensively used as a standard in the United States. This cell, which was devised by Latimer Clark, and bears his name, is composed of pure mercury, on which floats a paste of mercurious sulphate, a plate of zinc resting on the paste. Contact with the mercury, which acts as the positive pole, is made with a platinum wire. The electro motive force is 1.457 volts.

The resistance of a circuit to the passage of an electric current varies directly as its length and inversely as its cross section. The ohm is represented approximately by the resistance of a galvanized iron wire, 100 metres in length and 4 millimetres in diameter, or by a column of mercury 1.05 metres long and one square millimetre section, or again by 48 metres of pure copper wire, 1 millimetre in diameter, at the temperature of zero, Centigrade. Standard resistances are made of silver platinum wire, the coils of which are separated from each other by sheets of hard rubber pierced with holes, the insulation being effected by the air. The coils thus composed are placed in a cylindrical box made from two copper capsules stamped out of the solid metal and screwed into each other; this apparatus can be submerged in water without detriment.

In a circuit of one ohm resistance, whose ends differ in potential by one volt, the intensity of the current which flows is equal to one ampère. In any circuit the intensity of the current is

$$\text{Ampères} = \frac{\text{volts}}{\text{ohms.}}$$

The coulomb is the quantity of electricity given by an ampère in a second. The quantity will also depend upon the electro motive force and the capacity of the body for holding or accumulating electricity, hence

$$\text{Coulombs} = \text{farads} \times \text{volts.}$$

Capacity is defined by the relation

$$\text{Farads} = \frac{\text{coulombs}}{\text{volts.}}$$

and hence

$$\text{Unit of capacity (the farad)} = \frac{\text{coulomb}}{\text{volt.}}$$

The farad is rather large, and consequently the microfarad is preferred for practical measurements of capacity. The microfarad is therefore 10^{-15} C. G. S. units of capacity.

The watt is now generally employed as the practical unit of electrical power. It is the power conveyed by a current of one ampère in one second through a conductor whose ends differ in potential by one volt. In other words,

$$\text{Current} \times \text{electro motive force} = \text{watts.}$$

A watt is equal to 10^7 absolute units of work or ergs.

The joule is the practical electrical unit of heat or work, being the heat generated by an electro motive force of one volt in a circuit of one ohm resistance; or in other words, the heat generated by a watt in a second. It is equal to 10^7 ergs.

It is advocated in the C. G. S. system of practical units to express each number as the product of two factors, one of them being a power of 10; and also to effect this in such a way that the exponent of the power of 10 shall be the characteristic of the logarithm of the number. Thus: 1,280,000 would be written as 1.28×10^6, and ·000,128 as 1.28×10^{-4}.

Following is a table of the electro magnetic units as given above, together with the formulæ of the magnetic and electro static system of units.

Electro Magnetic System of Units.

Name of Quantity.	Symbol.	Dimensions of Units.
Quantity of electricity.........................	Q	$L^{\frac{1}{2}}M^{\frac{1}{2}}$
Strength of the electric current..................	C	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$
Electro motive force..........................	E	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$
Resistance of conductor........................	R	LT^{-1}
Capacity......................................	K	$L^{-1}T^{2}$

Practical Units.

Unit of	Name.	Number of Absolute Units in One Practical Unit.	Definitions of Units.
Resistance.........	Ohm.....	10^9	Resistance of a column of mercury 10 sq.-millimetre section and 105 centimetres long.
Electro motive Force	Volt.....	10^8	Nearly that of a Daniell cell.
Current............	Ampère..	10^{-1}	Current of a volt through an ohm.
Quantity...........	Coulomb..	10^{-1}	An ampère for a second.
Capacity...........	Farad....	10^{-1}	Unit quantity at unit potential.
Power.............	Watt.....	10^7	Power conveyed by an ampère in a second through a volt.
Heat..............	Joule.....	10^7	Heat generated by a watt in a second.

Derived Magnetic Units.

Name of Quantity.	Symbol.	Dimensions of Units.
Strength of the pole of a magnet................	M	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$
Moment of a magnet.........................	Ml*	$L^{\frac{5}{2}}M^{\frac{1}{2}}T^{-1}$
Intensity of a magnetic field....................	I	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$

Electro Static System of Units.

Name of Quantity.	Symbol.	Dimensions of Unit.	Value in Electro-Magnetic Units.
Quantity of electricity...............	q	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$	vQ†
Strength of electric current..........	c	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	vC
Electro motive force................	e	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	$E \div v^2$
Resistance of conductor.............	r	$L^{-1}T$	$R \div v^2$
Capacity.........................	k	L	v^2k

* l = length between poles.

† $v = 3+10^{10}$ centimetres per second approximately, and is the ratio of the electro magnetic to the electro static unit of quantity.

ELECTRICAL WORK.

An electric current may be employed to do work of various kinds—chemical, magnetic, mechanical and thermal; and in every case where it does work it is done by the expenditure of a portion of the energy of the current. Ohm's law shows that the current produced by a given electro motive force is diminished in strength by anything that increases the resistance of the circuit; but the strength of the current may also be diminished, in certain cases, by another cause, namely, the setting up of an opposing electro motive force in the circuit. Thus, in passing a current through a voltameter, there is not only a diminution due to the resistance of the voltameter itself, but also a further diminution due to the opposing electro motive force—commonly referred to as polarization—which is generated while the chemical work is being done. So, again, where a current is used to drive an electro dynamic motor, the rotation of the motor will itself generate a counter current, which will diminish the strength of the working current. Whatever current, however, is not expended in this way in external work is developed as heat, either in the source of the electricity or in some other part of the circuit, or both. Heat, in fact, appears wherever the circuit offers a resistance to the current.

DEVELOPMENT OF HEAT BY ELECTRIC CURRENTS.

The number of units of heat developed in a conductor is proportional, 1st, to its resistance; 2d, to the square of the strength of the current; and 3d, to the time that the current lasts. The total quantity of heat developed in a circuit in the unit of time may be expressed by the formula

$$H = C^2R = \frac{E^2}{R} = CE,$$

where H is the quantity of heat produced, C the current, R the resistance, and E the electro motive force. So, also, if we consider any particular portion of a circuit the resistance of which is r, and where the difference of potential at the two ends of this section is e, then the quantity of heat developed in this portion of the circuit in the unit of time may be expressed by the formula

$$h = C^2r = \frac{e^2}{r} = eC.$$

The mechanical equivalent of the gramme degree heat unit, viz.: the amount of heat necessary to raise the temperature of 1 gramme of water 1 deg. C., is 4.2×10^7 ergs.

$$\text{One gramme degree} = 4.2 \times 10^7 \text{ ergs.}$$

$$\text{One joule} = 10^7 \text{ ergs.}$$

$$\text{One joule} = \frac{1 \text{ gramme deg.}}{4.2} = 0.238 \text{ gramme degrees.}$$

In other words, the mechanical equivalent of the quantity of heat developed in t units of time in a circuit, the resistance of which is R, by a current of strength C, is given by the equations

$$W = JH = C^2 R t \text{ ergs},$$

where J is Joules' dynamical equivalent of heat and H the heat in gramme degrees.

This law may be arrived at by the following calculation: The work W done by a current in moving Q units of electricity against an electro motive force E, is:

$$W = Q E,$$

and since $Q = C t$, and $W = J H$, we have:

$$JH = C t E = C^2 R t,$$

$$\text{Whence } H = \frac{C^2 R t}{J.}$$

But as C and R are here in absolute units, they must be multiplied by $10^{-2} \times 10^9 = 10^7$, to reduce to the ordinary case of ampères and ohms, whence

$$H = C^2 R t \div 4.2 = C^2 R t \times 0.238.$$

This is equivalent to the statement that a current of one ampère per second, flowing through a resistance of one ohm, develops therein 0.238 gramme degrees per second.

The second of the above laws, that the heat is proportional to the square of the strength of the current, often puzzles young students, who expect the heat to be proportional to the current simply. But the consumption of zinc in a battery is also proportional to the square of the current; for, suppose that in working through a high resistance (so as to get all the heat developed outside the battery), we double the current by doubling the number of battery cells, there will be twice as much zinc consumed as before in each cell, and as there are twice as many cells as at first, the consumption of zinc is four times as great as before.

In any case, in order to double the current in a circuit of fixed resistance, we would have to double the electro motive force. Let us suppose a circuit in which flows a current, C, due to an electro motive force, E, then, according to one of our definitions, the heat developed in the circuit would be

$$H = C E.$$

Now let the current be doubled by doubling the electro motive force, and

$$H = 2 C \times 2 E = 4 C E,$$

which plainly shows that in doubling the current the heat has been increased fourfold, or as the square of the current.

Mechanical Work by Currents.—If an electro magnetic motor be introduced into a circuit in which there is an electro motive force E, the rotation of the motor will itself generate a counter electro motive force e. Calling the total resistance of the circuit R, the current flowing may be expressed by the following equation:

$$(1) \qquad C = \frac{E - e}{R}$$

Now this current is developing not only a certain amount of heat in the circuit, but it is also doing mechanical work in overcoming the motor's friction, and perhaps driving machinery. The energy appearing as heat will be:

$$(2) \qquad H = C^2 R.$$

The energy appearing as mechanical work may be represented thus:

$$(3) \qquad w = C e.$$

The total work done by the current is, therefore, equal to the sum of these two, that is:

$$(4) \qquad W = C^2 R + C e$$

Whence $(5) \qquad W = C E$

For $R = \frac{E - e}{C}$

And substituting this value in (4)

$$W = C^2 \left(\frac{E-e}{C} \right) + C e$$

Whence $W = C E$

If this mechanical work were transformed into its equivalent of heat, and this heat were added to that developed in the circuit, the sum of the two would exactly equal the total amount of heat which would have been generated in the circuit had a resistance been substituted for the counter electro motive force of such a value as to maintain the current strength unaltered.

Chemical Work by Currents.—If a secondary battery be charged by an electro motive force E, and itself opposes a counter electro motive force e, the chemical work done in charging the battery is:

$$w = C\,e$$

And the work appearing as heat will be:

$$H = C^2\,R$$

Where R is the total resistance of the circuit.

The total work done in the circuit is clearly the sum of these two.

$$W = C\,e + C^2\,R = C\,E$$

The heat equivalent to the chemical work done, if added to the heat due to the resistance of the circuit, would exactly equal the heat which would have been generated by the current in this circuit had an equivalent resistance been substituted for the counter electro motive force.

The counter electro motive force due to the motor and that of the battery are thus identically the same in their effect.

Rise of Temperature.—The elevation of temperature in a resisting wire depends on the nature of the resistance. The resistance of a short length of thin wire may be just the same as a long length of thick wire, in which case each will cause the same number of units of heat to be evolved; but in the former case, as they are spent in heating a short thin wire of small mass they will cause it to get very hot, whereas in the latter case they will perhaps only warm to an imperceptible degree the mass of long thick wire. If the wire weigh w grammes, and has a specific capacity for heat s, then

$$H = s\,w\,d,$$

where d is the rise of temperature in degrees centigrade. Hence

$$d = 0.24 \times \frac{C^2\,R\,t}{s\,w}$$

Since the resistance of metals increases as they rise in temperature, a thin wire heated by the current will resist more and grow hotter and hotter until its rate of loss of heat by conduction and radiation into the surrounding air equals the rate at which heat is supplied by the current.

Thin wires heat much more rapidly than thick, the rise of temperature in different parts of the same circuit being, for different thicknesses of wire, inversely proportional to the third power of the diameter.

Thus, suppose a wire at any point to become reduced to half its diameter, the cross section will have an area $\frac{1}{4}$ as great as in the thicker part. The resistance here will be 4 times as great, and the number of heat units developed will be 4 times as great as in an equal length of the thicker part. But 4 times the amount of heat requires 4 times the radiation, and the radiating surface having been reduced $\frac{1}{2}$, the metal will warm to a degree 8 times as great, and $8 = 2^3$.

Mechanical Equivalent of Currents.—The mechanical work of a current may be calculated as follows: A current whose strength is C conveys through the circuit in t seconds a quantity of electricity $= C\,t$. But the number of ergs of work W, done by a current is equal to the product of the quantity of electricity into the difference of potentials through which it is transferred, provided these latter are expressed in absolute C. G. S. units, or

$$W = C\,t\,V.$$

Now, if W ergs of work are done in t seconds, the rate of work is got by dividing W by t; whence

$$C\,V = \frac{W}{t}$$

If C and V are expressed in ampères and volts, respectively, and it is desired to give the rate of working in horse power, it must be remembered that 1 ampère $= 10^{-1}$ C. G. S. units of current; that 1 volt $= 10^8$ absolute units of electro motive force, and that 1 horse power $= 550$ foot-pounds per second $= 76$ kilogrammetres per second $= 76 \times 10^5$ gramme-centimetres per second $= 746 \times 10^7$ ergs per second, whence

$$\frac{\text{C ampères} \times \text{V volts}}{746} = \text{rate of doing work in H. P.}$$

Chemical Work by Currents.—The amount of chemical action is equal at all points of a circuit. If two or more electrolytic cells are placed at different points in a circuit, the amount of chemical action will be the same in all, for the same quantity of electricity flows past every point of the circuit in the same time. If all these cells contain acidulated water, the quantity, for example, of hydrogen set free in each will be the same; or, if they contain a solution of sulphate of copper, identical quantities of copper will be deposited in each. If some of the cells contain acidulated water, and others contain sulphate of copper, the weights of hydrogen and of copper will not be equal, but will be in chemically equivalent quantities.

The amount of an ion liberated at an electrode in a given time is proportional to the strength of the current. A current of 2 ampères per second will cause just twice the quantity of chemical decomposition to take place as a current of 1 ampère per second would do in the same time.

The amount of an ion liberated at an electrode in one second is equal to the strength of the current multiplied by the electro chemical equivalent of the ion. It has been found by experiment that the passage of 1 ampère of electricity through water liberates .0000104 gramme* of hydrogen; hence a current whose strength is C will liberate C × .0000104 grammes of hydrogen per second. The quantity .0000104 is called the electro chemical equivalent of hydrogen. The electro chemical equivalent of other elements can be easily calculated if their chemical equivalent† of copper is 31.5; multiplying this by .0000104, we get as the electro chemical equivalent of copper the value .0003276 (grammes).

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* Kohlrausch and Lord Rayleigh say .00001035; Mascart says .000010415.

† The chemical equivalent must not be confounded with atomic weight.

Table of Electro Chemical Equivalents.

	Atomic Weight.	Valency.	Chemical Equivalent.	Electro Chemical Equivalents (Grammes per Ampère.)
Electro positive:				
Hydrogen	1.	1	1.	.0000104
Potassium	39.1	1	39.1	.0004105
Sodium	23.	1	23.	.0002415
Gold	196.6	3	65.5	.0006875
Silver	108.	1	108.	.0011340
Copper (Cupric)	63.	2	31.5	.0003276
" (Cuprose)	63.	1	63.	.0006615
Mercury (Mercuric)	200.	2	100.	.0010500
" (Mercurose)	200.	1	200.	.0021000
Tin (Stannic)	118.	4	29.5	.0003097
" (Stannose)	118.	2	59.	.0006195
Iron (Ferric)	56.	4	14.	.0001470
" (Ferrose)	56.	2	28.	.0002940
Nickel	59.	2	29.5	.0003097
Zinc	64.9	2	32.5	.0003407
Lead	207.	2	103.5	.0010867
Electro negative:				
Oxygen	16.	2	8.	.0000840
Chlorine	35.5	1	35.5	.0003727
Iodine	127.	1	127.	.0013335
Bromine	80.	1	80.	.0008400
Nitrogen	14.	3	4.3	.0000490

APPARATUS FOR MEASURING POWERFUL CURRENTS.

Since the applications of electricity have been so largely developed for industrial purposes requiring currents of great intensity, the necessity has arisen for appliances by which the value of the currents employed, whether for electro plating, for the production of light, or for the transmission of power, can be determined. From a scientific point of view, the subject is one of great interest, while commercially it is one of great moment, as accurate measurements form the basis of commercial success in this, as in any other branch of engineering.

The difference between the apparatus required to measure the currents employed in electric lighting, and that heretofore used in scientific investigations, telegraphy, etc., is, for the most part, one of degree only. The former were designed to detect and measure extremely feeble currents, whereas the latter are required to indicate very slight changes in powerful currents. The coils of such instruments must therefore be sufficiently large to carry without appreciable heating, the strongest current they may be intended to measure.

For measuring the intensity of currents in absolute units, either the tangent galvanometer or the electro dynamometer, in one form or another, is employed in all laboratory work.

Perhaps the simplest method of measuring current strength is by means of the tangent galvanometer, the measurement being made by comparing the deflection given by the current whose strength is required with the deflection given by a current of known strength.

The most reliable current measurers used in general electric lighting work are modifications of the tangent galvanometer. Practically it is generally preferred to use galvanometers specially constructed for this purpose, and graduated beforehand in ampères by the maker; such galvanometers are called ampère-meters or ammeters.

Most of these instruments have the magnetized needle suspended in a more or less powerful magnetic field, usually a form of horseshoe magnet. They are open to the objection that, owing to the inconstancy of the magnetic field, they have to be frequently calibrated. Again, the arbitrary division of their scales—necessitated by the fact that no function of the angle of deflection is proportional to the current producing the deflection—is a possible source of error. Those not so divided require to be calibrated for each division—a decidedly inconvenient arrangement.

These galvanometers are, however, sufficiently accurate for the general requirements of industry; and as they are portable, their indications almost instantaneous, and their employment requires neither study nor calculation, they are very convenient.

For the direct measurement of resistance, the ordinary methods and apparatus are, of course, applicable to all cases.

Before describing the various forms of measuring apparatus we desire to call attention to an important fact in connection with electrical measurements, which is continually overlooked, viz.: that if accuracy is required, every apparatus must be adjusted and arranged for the particular measurements that are to be made. Many galvanometers have been devised for giving the strength of a current by a direct reading, and without the use of resistance coils or shunts; such galvanometers can only give accurate results within a very limited range of their scale, and are almost useless for making measurements beyond that range. Thus a galvanometer which indicates accurately a current of 25 ampères will not be nearly so accurate if the deflection indicates 50 ampères on the one hand or 10 ampères on the other. For general purposes simplicity is certain to be obtained at the cost of accuracy, and practical men who so often say that an apparatus for testing is of no use unless it is simple, will find that this simplicity is the cause of far greater errors and untrustworthy results than would follow the use of properly designed apparatus, even if a little more complicated, and which, besides, would not require an extraordinary amount of intelligence or skill to manipulate.

By the calibration of a galvanometer is meant the determination of the value in ampères of each division of its scale. In other words, it is the standardization of the instrument. For example, suppose we have a galvanometer in which the deflections are proportional to the strength of current, and a current known to be equal to 2 ampères produces a deflection of 4 divisions; by dividing the current by the number of divisions, we find that each division of its scale represents one half ampère, that is,

$$\frac{2 \text{ ampères}}{4 \text{ degrees}} = 0.5 \text{ ampère},$$

which is called the constant of the galvanometer. Any deflection of the needle multiplied by the constant will give the value in ampères of the current producing that deflection.

If in the preceding case the instrument had been a tangent galvanometer with its scale divided into degrees—in which case the current strengths are proportional to the tangent of the angle of deflection—and a current of 10 ampères produced a deflection of 20 degrees, we would proceed as before to find the constant, using tangents of degrees instead of divisions. Thus, the tangent of 20 degrees is 0.36397, and

$$\frac{\text{Current}}{\text{Tangent of degrees}} - \frac{20}{0.36397} = 55 \text{ nearly} = \text{constant.}$$

The tangent of any deflection multiplied by the constant gives the value in ampères of the current producing the deflection, which is expressed by the equation:

$$C = \text{tang. } d^\circ \times \text{constant,}$$

where d° is the deflection in degrees.

All galvanometers designed for measuring current strength will also measure electro motive force; for if the resistance of a circuit remains constant, any increase in the current can only be due to a corresponding increase in the electro motive force, and the measure of the current must be also the measure of the electro motive force.

As a matter of fact, the resistances of circuits differ so widely that it would be, evidently, of little use to calibrate a galvanometer to read volts in a circuit of given resistance. But we know that the difference of potential between any two points of a circuit in which a given current flows is proportional to the resistance between them, so that if we connect a galvanometer to those points it will indicate the electro motive force due to that difference of potential; so likewise if it were placed across the poles of a battery or dynamo electric machine supplying current to a circuit, it would indicate the difference of potential between the two ends of that circuit. If, however, the resistance of the galvanometer were small, it would not only divert too much of the current from the circuit, but would also reduce the resistance, and consequently the potential, between the points to which it was attached; hence it is desirable to have its resistance as high as possible. It will be seen from this that ammeter readings should not be taken while the potential measurer is in circuit. Galvanometers to be used in this manner for measuring electro motive force, when calibrated in volts, are called voltmeters.

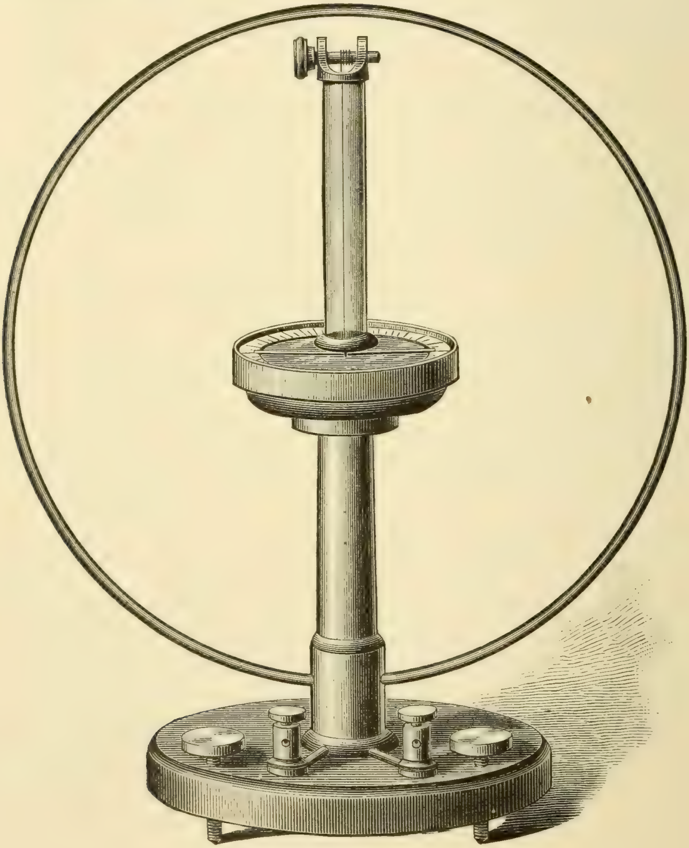

Fig. 498.

THE TANGENT GALVANOMETER.

One of the simplest forms of tangent galvanometers, suitable for measuring powerful currents, is shown in fig. 498.

It consists of a ring of stout copper wire, a foot or more in diameter, the two extremities of which are bent to connect with binding posts. At the centre is delicately suspended a magnetized steel needle, not exceeding one inch in length, and usually furnished with a light index of aluminum, which indicates upon a horizontal scale graduated in degrees of arc, or into divisions corresponding to the tangents of such degrees, the angular movements of the needle. In the figure the needle is suspended by a silk fibre, but it is frequently supported by a fine pivot, a jeweled bearing being fixed in the needle. The instrument is adjusted by setting the coil in the magnetic meridian, the small needle lying then in the plane of the coil. One essential feature of this arrangement is, that while the coil is very large, the needle is relatively very small. The field due to a current passing round the ring is very uniform, and the needle being small, its poles are never far from the centre. Whatever magnetic force the current in the coil can exert on the needle is exerted normally to the plane of the ring, and therefore at right angles to the magnetic meridian. Now, the magnetic force which, acting at right angles to the meridian, produces on a magnetic needle a certain deflection, is equal to the horizontal force of the earth's magnetism at that place multiplied by the tangent of the angle of deflection. Hence a current flowing in the coil will turn the needle aside through an angle such that the tangent of the angle of deflection is proportional to the strength of the current.

To increase the range of this form of galvanometer, so as to be able to measure currents of widely different intensities, the ring may be constructed with two or more turns of wire, with their ends so arranged that they may be readily connected together in series or in multiple arc as the case may require.

Currents are led to the instrument by means of a twisted flexible cable, which is perfectly inactive upon magnetic needles, and therefore termed an adynamic lead.

In using a tangent galvanometer, it is preferable to obtain deflections as near 45° as possible. The reason for this is, that any small change in the strength of a current traversing the galvanometer will produce the greatest effect on the needle when the latter stands at that angle. A slight error in reading either very great or very small deflections may cause a serious error in the results.

We would particularly point out that the accuracy of the tangent galvanometer does not depend upon the constancy of permanent magnets or of springs; nor has the needle to be shifted for measuring different current strengths—a procedure by which the magnetic field is mostly affected.

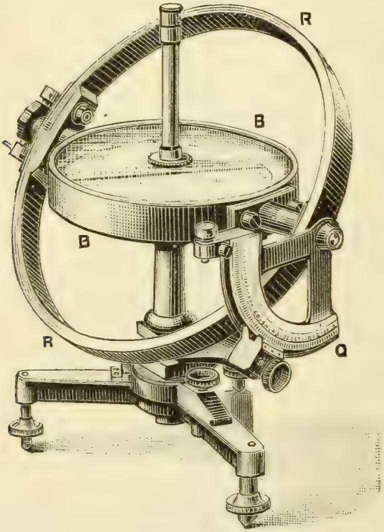

Fig. 499.

OBACH GALVANOMETER.

Another instrument for measuring the strength of powerful currents with great accuracy, is the Obach galvanometer, shown in fig. 499. It is a tangent galvanometer with a ring movable round a horizontal axis lying in the magnetic meridian. The principle can be best explained by reference to the diagram shown in fig. 500. If a small magnetic needle, freely movable in any direction, is suspended in the centre of a circular coil, through which a current is passing, the following is observed: If the current ring is in a vertical position, A, the needle is only acted upon by a couple which tends to turn it round a vertical axis; the opposing force is the horizontal component of the earth's magnetism. If the ring is in a horizontal position, B, the needle no longer leaves the meridian, but is merely turned round a horizontal axis or dipped. The opposing force is now the vertical magnetic component of the earth. For any intermediate position, C, of the ring between the vertical and the horizontal, the needle is at the same time deflected from the meridian, and more or less dipped. If by any means the needle is prevented from exercising the dipping motion, the instrument can be used for the measurement of currents of widely different strengths by placing the ring for each current in such a position that the needle is deflected to that part of the scale where the readings are most accurate, viz., near 45°. For any fixed position of the ring, the current strength is proportionate to the tangents of the deflections, as is the case with the vertical ring of the ordinary tangent galvanometer. If, on the other hand, the currents are compared by giving the ring in each case such an inclination that the needle always points to the same degree,

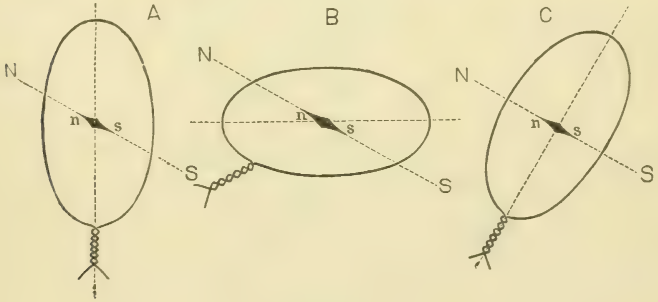

Fig. 500.

say, for instance, 45°, 30°, 15°, then the cosecant of the angle between the ring and the horizontal plane determines the ratio of current strength. If the angle between the ring and the vertical plane is measured, the secant takes the place of the cosecant. A check on the two methods of measurement is thus at hand.

If currents are compared at different inclinations, *a*, of the ring, giving at the same time different deflections, *d*, the tangent of the deflection divided by the sine of the corresponding inclination measures the current strength. Thus, for three different current strengths,

$$S_1 : S_2 : S_3 = \frac{\tan. d_1}{\sin. a_1} : \frac{\tan. d_2}{\sin. a_2} : \frac{\tan. d_3}{\sin. a_3}.$$

If the same current is measured at different inclinations, the fraction

$$\frac{\tan. d}{\sin. a},$$

must of course be a constant value, and this affords an excellent means of testing the degree of accuracy of the measurements through the entire range of the instrument. These means of controlling the results form an advantage, which, so far as we know, is not shared by any other current measuring instrument yet devised. The needle was formerly prevented from dipping by pivoting the axle at both ends in jewel bearings. This plan has lately been abandoned in favor of the following arrangement: A small vertical axle, on which the needle is fixed, is provided with a little cylindrical leaden weight at the lower end. This adds but little to the momentum of the needle round the vertical axis, whereas a great power is required to lift it up by a dipping motion. The needle, with its aluminum pointer and the little weighted axle, is suspended by means of a cocoon fibre. The ring, made of gun metal or brass, is about 15 inches in diameter.

This instrument is also constructed as shown in fig. 501, so as to be equally suitable for measuring electro motive force and current strength. For this purpose it has a grooved metal ring on which a coil of German silver wire is wound. The number of convolutions are so chosen that the electro motive force of one volt produces exactly the same deflection with the fine wire coil

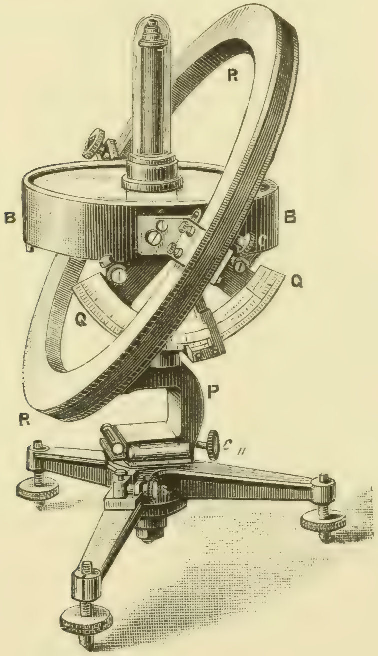

Fig. 501.

as the current of one ampère with the solid ring. This simple relation is very convenient for calibrating the galvanometer.

The change of the constant, when the instrument is taken from one place to another, is avoided by a compensating magnet placed east or west from the needle and parallel to the meridian. This magnet—which is shown in fig. 502—can be turned on a horizontal axis passing through its centre and through that of the needle; it is entirely inactive if vertical, whereas it acts upon the needle if it is more or less dipped, without, however, interfering with the zero position. By giving the magnet a proper dip, the constant can always be kept at the same value.

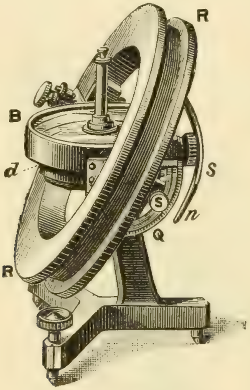

Fig. 502.

The vertical scale showing the position of the coil has, in addition to the usual degrees, a number of divisions engraved upon it which correspond to natural secants.

DEPREZ AMMETER.

As a representative type of the industrial instruments to which we have referred, the Deprez ammeter will serve as an excellent example. Its principle is illustrated in fig. 503. Between the poles of a powerful horseshoe magnet is placed a small oval coil, consisting of several layers of rather large silk covered copper wire. Within the coil a small magnetized needle swings about a vertical axis. Attached to the axis, at right angle to the needle, is a long aluminum pointer, under the extreme end of which a graduated scale card is placed. The coïl is usually wound in two parts, the ends being joined in parallel circuit and brought to the binding posts. This instrument is almost dead beat in its action, owing to the extreme lightness of the needle and aluminum pointer and to the great strength of the magnetic field. The scale is graduated arbitrarily, and the currents to which its divisions correspond are generally determined by the maker and written on a card accompanying the ammeter.

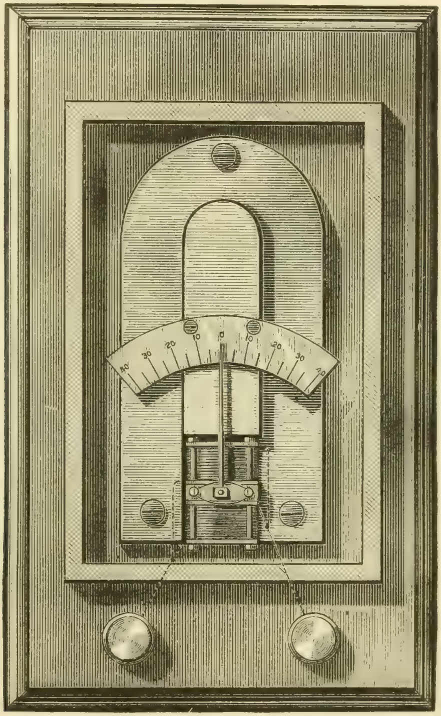

Fig. 503.

This instrument is converted into a voltmeter by winding the coil, with very fine wire, to a high resistance.

Another form of the Deprez ammeter is illustrated in fig. 504, which shows on the left the external appearance of the instrument, and on the right the internal arrangements. The axis of the coil is placed—not, as is usual in galvanometers—at right angles to the axis of the magnetic field, but at an acute angle with it, so that, instead of, as is usually the case in ordinary galvanometers, the magnetic moment due to the current diminishing as the needle is deflected, while that due to the permanent controlling field increases, and in consequence of which the current must increase much more rapidly than the deflection, the plan of sloping the coil causes the magnetic moment due to the currents to increase up to a certain point. The axis of the needle is pivoted at both ends.

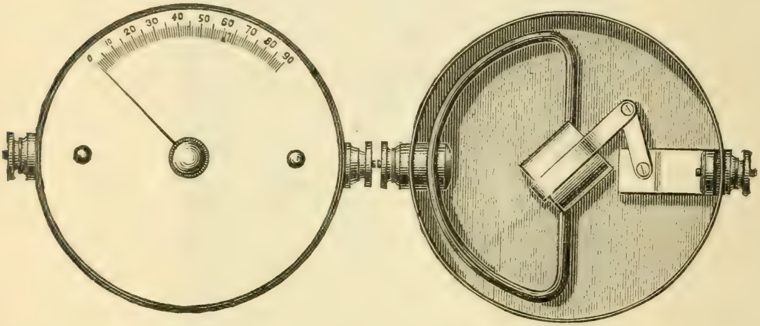

Fig. 504.

AYRTON AND PERRY'S COMMUTATOR AMMETER.

This instrument, fig. 505, contains a coil consisting of ten strands, each of exactly the same resistance. These ten strands, by means of a simple commutator, can be joined either in series or in parallel circuit, and so the sensibility of the instrument can be increased exactly ten times. The resistance of each strand is about 0.03 ohms, so that when in series the instrument has 0.3 ohms, and when parallel 0.005 ohms, the latter figure being increased about 0.002 ohms by the resistance of the connections. The needle and pointer are pivoted by an axis passing through their common centre of gravity, so that the deflection is unaltered, no matter in what position the instrument may be held, and, the pivot resting in jewels top and bottom, the friction is also practically unaltered by turning the instrument on its side or holding it upright. The needle is placed between the poles of a large compound magnet, which is so strong that the ammeter may be placed not very far from even a dynamo machine in action, without the magnetism of the machine affecting the indications of the instrument. For the purpose of calibrating the instrument, a coil of 1 ohm resistance is placed in its base, which may be added to the circuit by the removal of the plug shown in the cut.

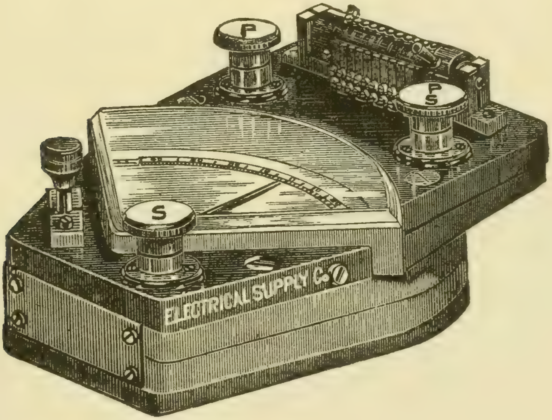

Fig. 505.

The high grade of sensibility is generally only used for the purpose of calibrating the instrument, but it is very convenient for measuring the comparatively small currents of 0.5 to 2 ampères used with incandescent lamps.

The instrument is so wound that, when a current is sent from binding screw to binding screw, at each side of the commutator, the pointer points to that binding screw at which the positive current enters.

Many of the instruments are adjusted to give 1 ampère per degree when the commutator is to parallel; others again are arranged to give 2 ampères per degree; while some go as high as 5 ampères per degree, and measure currents of over 200 ampères.

AYRTON AND PERRY'S COMMUTATOR VOLTMETER.

The commutator voltmeter of Ayrton and Perry differs only from their commutator ammeter in the resistance of the coils. In this case each coil has a resistance of 200 ohms, so that when in series the instrument has 2,000 ohms resistance, and when parallel only 20 ohms, the resistance coil being also 20 ohms. The voltmeter is calibrated in parallel circuit and used generally in series, and then indicates from 1 volt per degree in some instruments to 5 volts per degree in others, the total deflection of 45° in the latter case corresponding with 225 volts. But just as the ammeter can be conveniently used in series, when testing the comparatively small currents passing through a single incandescent lamp, so the voltmeter may be used in parallel circuit for testing electro motive forces of 2 or 3 volts, such as, for example, the electro motive force of one or two storage batteries.

In the ammeter the resistance coil can be introduced in the circuit only when the commutator is to series, and in the voltmeter only when to parallel, so that in neither case can it be fused by the plug being accidentally taken or left out when a strong current, or, in the second case, a large electro motive force is being measured. To avoid the coils of the instruments themselves being fused, or the pointer being damaged by too large a deflection, precautions are taken by the use of three distinct binding screws in each.

AYRTON AND PERRY'S NON-COMMUTATOR AMMETER AND VOLTMETER.

Fig. 506 shows another form of Ayrton and Perry's ammeter and voltmeter. In these instruments the commutator is dispensed with and the coils are connected in parallel circuit in the ammeter and in series in the voltmeter, permanently. In other respects they are substantially the same as the commutator instruments. Owing to the small deflection given by a standard cell with these instruments, they are not so readily calibrated as the commutator form, and they are more especially intended to be used in places where many ammeters and voltmeters are employed, and where it is, of course, unnecessary that all should be provided with commutators for easy calibration. It is sufficient that a few of the ammeters and voltmeters should have commutators for independent calibration, the remainder being calibrated by direct comparison with those having commutator attachments.

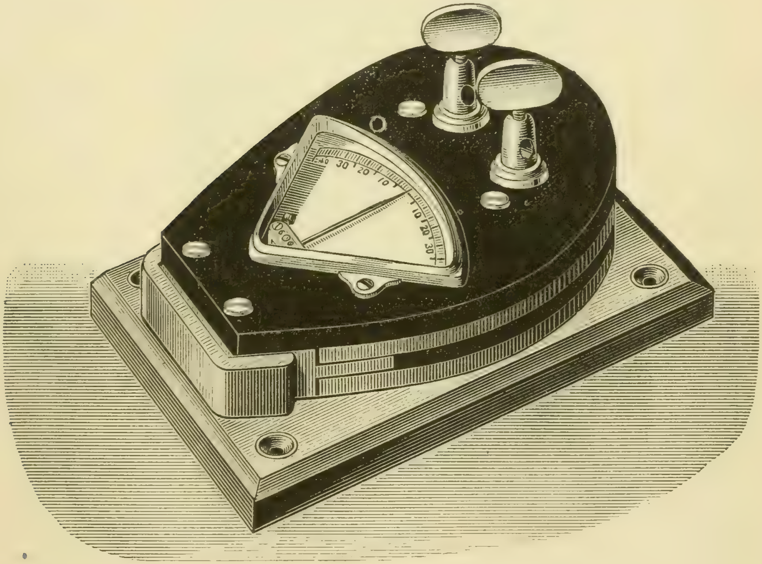

Fig. 506.

To partially avoid the loss of magnetism in the controlling permanent magnets, an armature or keeper, shown in the cut, is provided with all of the instruments, but which, of course, must be removed when the instruments are in use.

In all of these instruments of Ayrton and Perry, which we have described, the deflections are presumed to be directly proportional to the currents producing them, and the current or electro motive force corresponding to one division of their scales is marked by the manufacturers upon the box accompanying every ammeter or voltmeter.

AYRTON AND PERRY'S SPRING AMMETER AND VOLTMETER.

We have already called attention to the necessity of frequently calibrating magnet instruments, to detect changes of magnetism in the permanent magnets which necessarily occur. As a matter of fact, good Daniell's cells or other reliable means of calibrating ammeters and voltmeters do not exist in many places where there are electric light installations, and consequently users themselves do not calibrate their instruments, but rely on the makers' figures.

To overcome this difficulty of loss of magnetism in the permanent magnets, Messrs. Ayrton and Perry have constructed ammeters and voltmeters like that shown in fig. 507, in which the controlling force is either a flat or cylindrical spiral spring, coiled about and attached to the axis of the needle, instead of the permanent magnet. In this case the axis of the soft iron needle makes an angle less than a right angle with the axis of the coil when no current is passing, since if it made a right angle it would be in unstable equilibrium when a current passed. The best angle that the axis of the needle should make with the axis of the coil when the pointer points to zero, has been determined partly by calculation and partly by experiment, and it is claimed that, with proper initial adjustment, deflections of the pointer up to 45° can be obtained directly proportional to the current.

These instruments possess two important advantages: the one being that they can be used with reverse currents; the second, that by giving any special set to the spring (for doing which there is a small hand seen in the figure, and which can be turned through any angle, indicated by a small graduated scale, A, under it), the needle does not start from the zero position until the current in the ammeter or electro motive force in the voltmeter exceeds a certain prearranged limit. This method of giving a set to the spring greatly increases the sensibility of the instrument.

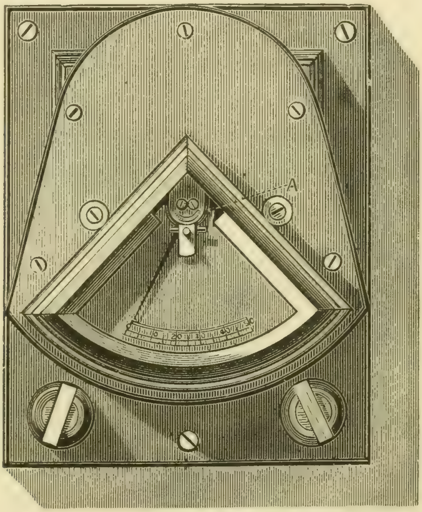

Fig. 507.

AYRTON AND PERRY'S WHEEL AND PINION AMMETER AND VOLTMETER.

When still greater delicacy is required, the form of the spring instrument is somewhat changed, as shown in fig. 508. Attached to the arbor of the needle is a wheel, W, with extremely fine cut teeth gearing into those of a pinion, P, on the arbor to which the pointer is attached. With this arrangement the motion of the pointer is magnified ten times. If, then, the coil and needle have such a shape, and the axis of the needle makes such a proper initial angle with the axis of the coil that the deflection of the needle up to not more than 36° is proportional to the current, then with the wheel and pinion arrangement the deflection of the pointer over the entire scale of 360° will be proportional to the current. In addition to these, both the arbor of the needle and the arbor of the pinion are provided with very

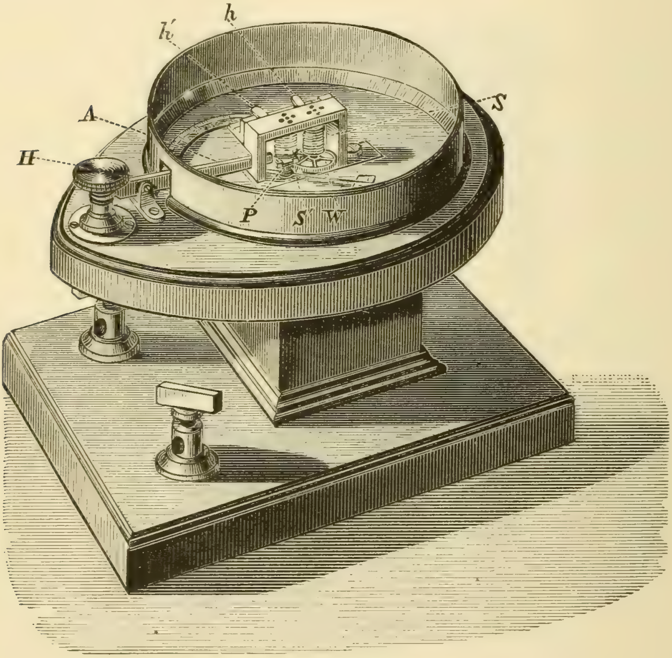

Fig. 508.

delicate cylindrical spiral springs, S, S′; one or both of which may be employed, since the latter can be thrown out of gear by raising the arm, A, which is done by turning the head, H, of the adjusting screw. If both the springs be of the same strength, then the sensibility of the instrument can be instantly made one hundred times as great by turning the milled head, H, which raises the arm, A, and throws S′ out of gear, or can be increased to any other known less or greater prearranged amount, by having the spring on the pinion weaker or stronger than that on the wheel. Both springs have, further, little hands, *h*, *h*′ (seen in the figure), for setting them up, so that the whole deflection of 360° may, if desired, be produced by a small percentage of change in the total current where it is wished to measure accurately small changes in a fairly constant current. Every bearing is jewelled. The coil and needle are placed in the supporting box and are not shown in the cut. The wheel and pinion ammeter furnishes an instrument for the measurement of strong currents, comparable in delicacy with the instruments usually employed for the measurement of only weak currents. An ammeter on this principle has been constructed to measure up to 1,200 ampères.

The voltmeters are constructed with two grades of sensibility, and measure electro motive force with great accuracy.

AYRTON AND PERRY'S OHMMETER.

The instrument, which is shown in fig. 509, is for the purpose of measuring the resistance of any part of an electric light circuit, while the current is flowing, and indicates the ratios of current and electro motive force at one reading. It consists of two coils, one of thick and the other of fine wire. Both coils are fixed, and with their axes at right angles to one another, and the current flowing through each acts on the same needle. Through the thick coil the whole current, C, flows, and through the fine coil a shunt current which measures the electro motive force, E, between the two ends of the part of the circuit the resistance of which it is required to measure; and the forces due to these two currents are at right angles to one another; hence the deflection of the needle may be made to measure $E \div C$, which is equal to R. By giving the proper mathematical shape to both coils and to the needle, the deflections of the instrument shown in the figure are found to be directly proportional to the values of $E \div C$, that is, to the values of the resistances to be measured.

When the instrument is not in use, there is no directing force acting on the needle, and the pointer therefore remains anywhere. On allowing the main current to pass through the thick coil, by means of the outer and larger binding screws, the axis of the needle instantly places itself along the axis of the thick coil, and the pointer stands at naught. If now wires be attached to each of the small binding screws belonging to the fine coil, and the other ends of these two be attached to the same point of the main circuit, the pointer still remains at naught, indicating that there is no resistance in the main circuit between the two points of attachment of the fine wires. If these wires be separated by the field magnets of the dynamo, the pointer at once moves to a number indicating the resistance of the field magnets. It will be seen that the resistance of any part of the circuit can be measured at any time without interfering with the main current. In practice, the ohmmeter is simply kept inserted anywhere in the main circuit, and when it is desired to measure the

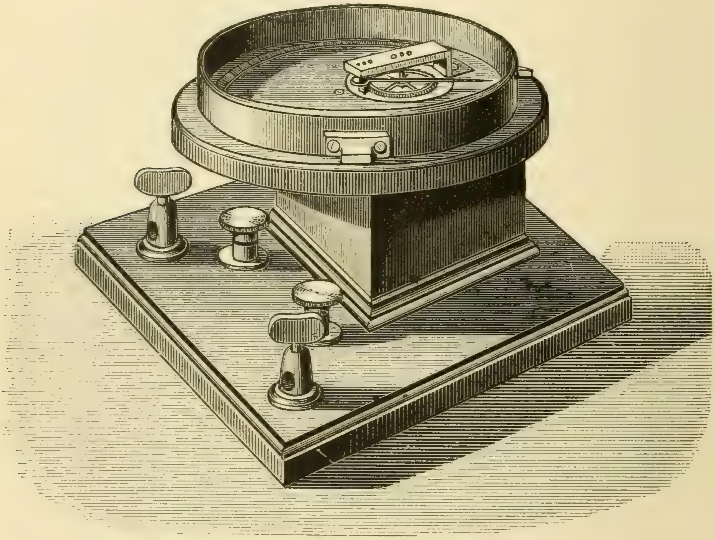

Fig. 509.

resistance of any part of the circuit, the two ends of this part of the circuit are connected by two fine wires to the two smaller binding screws of the ohmmeter. When the wheel and pinion are employed, a deflection of about 320° of the pointer is obtainable, a deflection of 60° corresponding with one ohm, so that measurement of resistance up to six ohms, correct to $\frac{1}{60}$ of an ohm, can be accurately and quickly made. The ohmmeter, it will be seen, dispenses with the use of resistance coils.

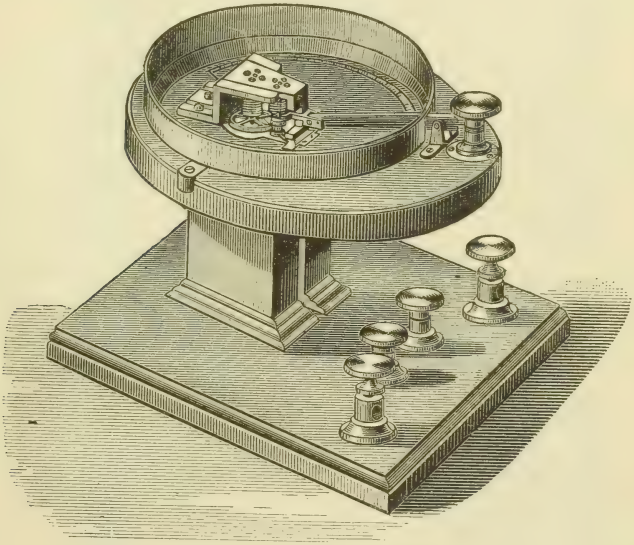

Fig. 510.

AYRTON AND PERRY'S ELECTRIC POWER METER.

This instrument, designed for measuring by one operation the horse power electrically given to any part of a circuit, is similar in some respects to the ohmmeter. The latter measuring the ratio E ÷ C, while the former measures the product C × E, and consequently the horse power which is proportional to C × E. Fig. 510 gives a general view of the instrument, which consists of a thick wire coil, through which the main current passes, and a fine wire coil suspended within it, which acts as a shunt to that part of the circuit of which it is desired to measure the electrical energy. The axis of the two coils are parallel, and the passage of a current tends to deflect the suspended one. Since the thick wire coil measures the intensity of the current, and the thin wire coil its electro motive force, as the deflection of the latter is the product of the two, the amount of that deflection is the measure of the power or energy of the current. Modifications of this instrument, with or without a commutator, or with a wheel and pinion arrangement, are also made.

HOPKINSON'S CURRENT METER.

Fig. 511 is a side view, with part shown in section, of the Hopkinson coulomb or current meter, and fig. 512 is a back view with case shown in section. In both figures *a a* are the electro magnets of a small dynamo electric machine to be used as a motor, *b* being its armature. This dynamo is wound with fine wire as a shunt to the current to be measured, part of which passes from L round the electro magnets, then through the armature, and thence by brushes and wire to the insulated ring, *h* (fig. 511). Here the circuit may be either made or broken, according as the movable piece or core, *i*, is raised or lowered. If this piece, which is a soft iron core within a solenoid, be lowered, the circuit is completed to the metal frame of the instrument through a vertical contact pin, *p*. This pin projects into a groove in the core, and forms a rubbing contact as the latter revolves.

The current to be measured passes through a solenoid of stout wire, *j*, enclosed in an iron tube, *k*, supported by the frame of the instrument. The vertical shaft, *l*, is driven by the armature of the dynamo and carries the iron core, *m m*, fixed to it. The iron core, *i*, revolves with the shaft, *l*, and can slide upon it. It is connected by links, *o o*, to the governor balls, *n n*, which therefore tend to raise it as the shaft revolves. The revolutions of the shaft are indicated by the worm and worm wheel, *q*, acting on the shaft and operating the pinions, *r r*, and hands of the

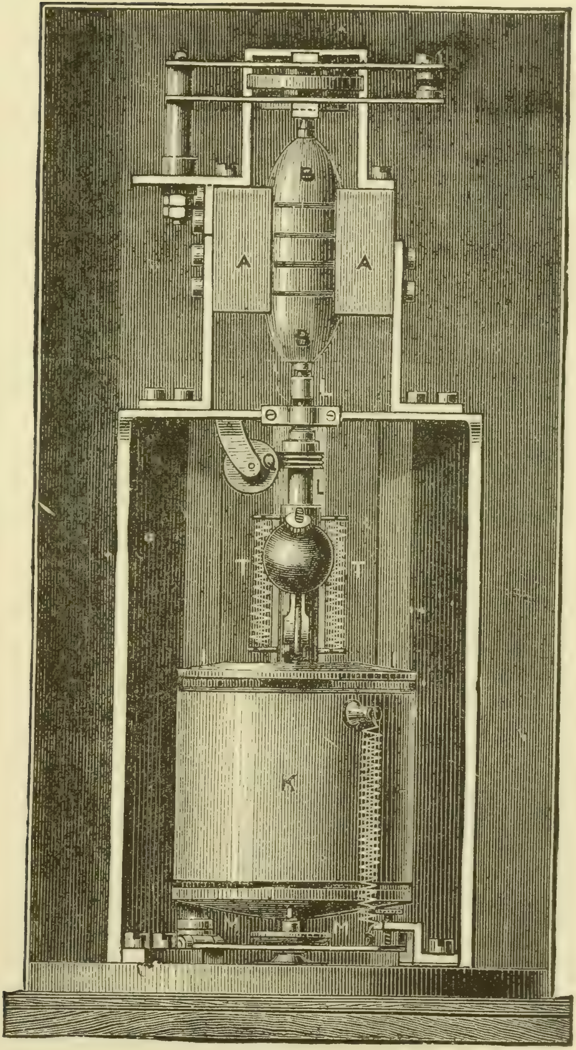

Fig. 511.

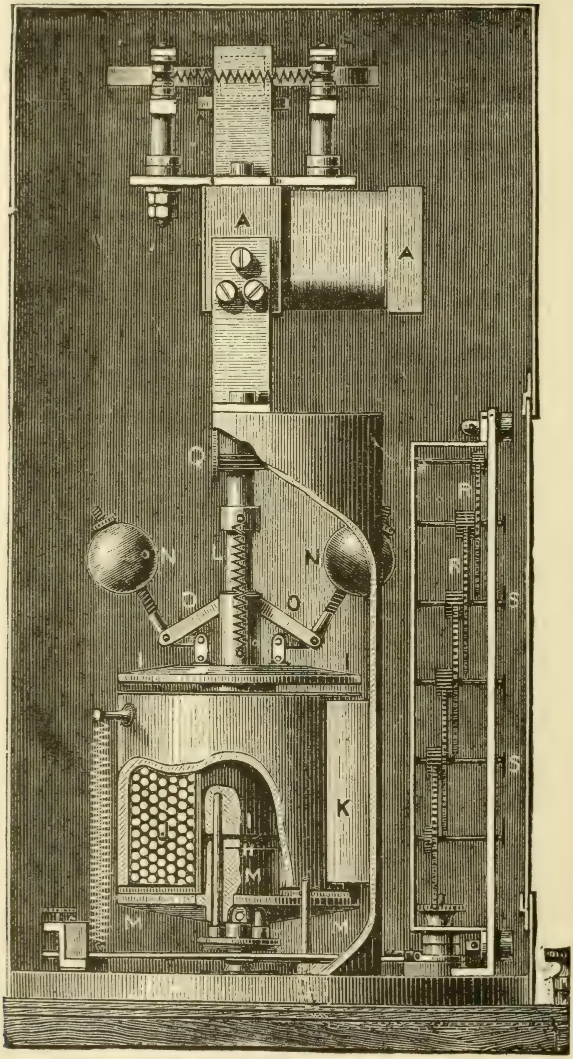

Fig. 512.

counter, *s*. Springs, *t*, take the weight of the core, *i*, and are so adjusted that when no current passes through the coil, *j*, contact is broken with the insulated ring, *h*; but a very small current through this coil will make the contact and cause the electro motor to begin to revolve. When a current passes through the coil, *j*, it causes attraction between the fixed tube, *k*, and the flanges of the moving cores, *m* and *i*, also between the cores, *m* and *i*. The magnetic force upon *i* is vertically downward, and is proportional within certain limits to the square of the current in the coil. When the governor is revolving the centrifugal force on the governor balls is proportional to the square of the speed of revolution, and tends to lift the core, *i*, in opposition to the magnetic force. These forces will exactly balance one another, for if the speed be too great, the circuit of the electro motor will be broken and the speed will fall. If it be too small, the electro motor will work and the speed will increase. The result is that the system will revolve with a velocity proportional to the current through the coil. Owing to the symmetrical arrangement of the cores, the electro magnetic forces are balanced as far as the shaft, *l*, is concerned, and they do not tend to put any pressure upon the bearings.

THOMSON'S GRADED CURRENT GALVANOMETER.

This instrument, which is shown in fig. 513, is designed to permit of a very wide range of measurement, being obtained by varying the intensity of the magnetic field in a known ratio and comparing with it the unknown current. It consists essentially of two parts, 1st, a coil, C, formed of a few turns of thick copper strips, with about $\frac{1}{1000}$ of an ohm resistance, through which the current to be measured is allowed to pass, it being vertically fixed to the end of a wooden platform, P, with about one half only of the coil projecting above it; and 2d, of a magnetometer, M. This last consists of four short steel magnets (constituting the needle) mounted in a frame on a vertical axis, with a long aluminum pointer attached, and enclosed in a quadrant shaped box, with a glass cover, and a silvered glass mirror bottom (in order to counteract any effect of parallax while reading the scale of tangents, to which the instrument is graduated).

In order to increase the directive force of the needle when required, a semicircular permanent magnet of hard steel, and of known intensity, may be attached vertically to two arms projecting from the magnetometer, behind the apex of the quadrant. The magnet stands over the needle, as shown in the figure, and its field is brought into parallelism with that of the earth, by turning the screw at the point of the magnet until the index points to zero. To avoid accidental demagnetization of the magnet, it must be kept at a distance from all other magnets.

The magnetometer is supported on three feet and a spring; two of these feet slide in a V groove, cut in a hard wood scale let into the tops of the platform, and this allows the magnetometer to be moved nearer to or further from the coil, but prevents it being so turned round as to change the zero reading of the instrument. The sensibility of the instrument is changed by varying the position of the magnetometer on the platform. When the front of the magnetometer (without the directing magnet) is placed at any division of the scale marked on the platform, the number stamped at that division indicates the deflection, in divisions of the magnetometer scale, produced by one ampère of current; the intensity of the magnetic field in which the magnetometer needles are placed being supposed unity. The abso-

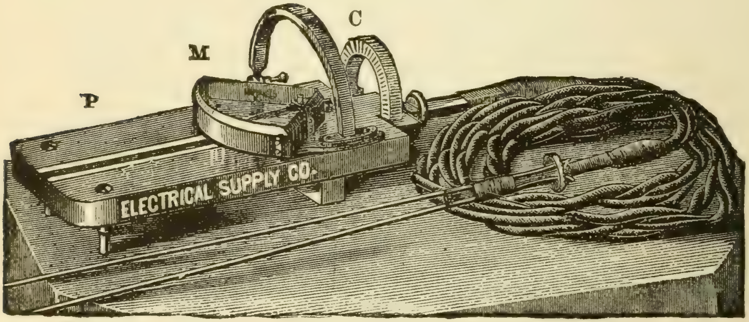

Fig. 513.

lute intensity of the magnetic field at the needle due to the directing magnet alone is carefully determined and marked on the magnet. The total intensity of the field is obtained by adding the horizontal component of the intensity of the earth's field, at the place in which the instrument is used, to the number marked on the magnet. A pair of flexible adynamic leads are supplied with the instrument. When in use the plane of the coil is placed in the magnetic meridian so that the index points to zero on the scale. The directing magnet is then placed in position and the adjusting screw turned until the index again points to zero.

The range of sensibility obtained by varying the extreme distance along the groove of the magnetometer from the coil is about fifty fold; while, by removing the magnet, and leaving the needle under the influence of the earth's force alone, a further sensibility of fifty times greater can be obtained. Any current whose intensity is less than 100 ampères may be safely measured by this instrument.

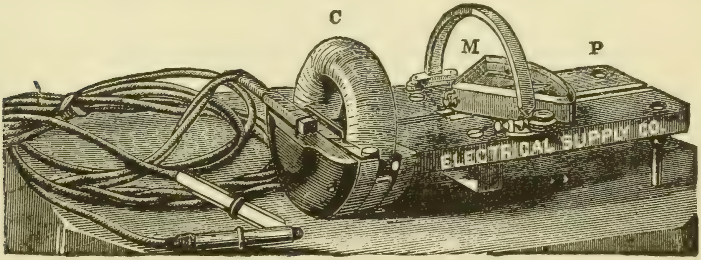

Fig. 514.

THOMSON'S POTENTIAL GALVANOMETER.

This instrument, shown in fig. 514, differs from the current galvanometer only in the coil, C, which is of thin German silver wire of about 5,000 ohms resistance. To prevent a current passing through the coil when no reading is being taken, a key, attached to the base of the instrument, is placed in circuit with it. A pair of flexible leads, with spring clips attached to their ends for making contact with two points of a circuit, accompany each instrument. Readings must be taken as quickly as possible, to avoid heating of the coil in this, as in other forms of voltmeters. When the front of the magnetometer is placed at any division of the scale marked on the platform, the number stamped at that division indicates the deflection in divisions of the magnetometer scale, produced by one volt difference of potential between the ends of the coil.

CARDEW'S GALVANOMETER FOR MEASURING LARGE CURRENTS AND VERY LOW RESISTANCES.

This instrument (fig. 515) is constructed on the principle of the differential galvanometer. A small coil of known resistance, consisting of many turns of fine wire, closely encircles a magnetized needle pivoted at its centre. Attached to the needle and at right angles to it is a horizontal pointer whose movements are limited by two vertical pins placed a fraction of an inch on each side of the zero point. Surrounding this fine wire coil is another coil of considerably greater diameter, composed of a few turns of thick wire.

The coils, which are of rectangular shape, are placed at one end of a rather long base board. Passing in under the coils, and in the same direction as they are wound, is a broad strap of copper; at each end of the coils this strap makes a right angle bend and continues on to the opposite end of the board, where the ends dip into mercury cup connectors. Three inches in front of the coils another transverse strap is placed, one end of which terminates in contact with one of the longitudinal straps, while the other bends at a right angle to terminate in a mercury cup as before. One end of the thick wire coil is in connection with a longitudinal strap, the other ends in a mercury cup. The fine wire is terminated at separate binding screws near the coils. These connections are shown diagrammatically in the figure. The copper straps are so placed that only the currents in the transverse straps affect the needle. It will thus be seen that three degrees of sensitiveness are obtainable: 1st, by connecting at mercury cups, 2 and 3, which throws in circuit the thick wire coil; 2d, by connecting at terminals, 2 and 5, which puts in circuit the transverse strap under the needle; 3d,

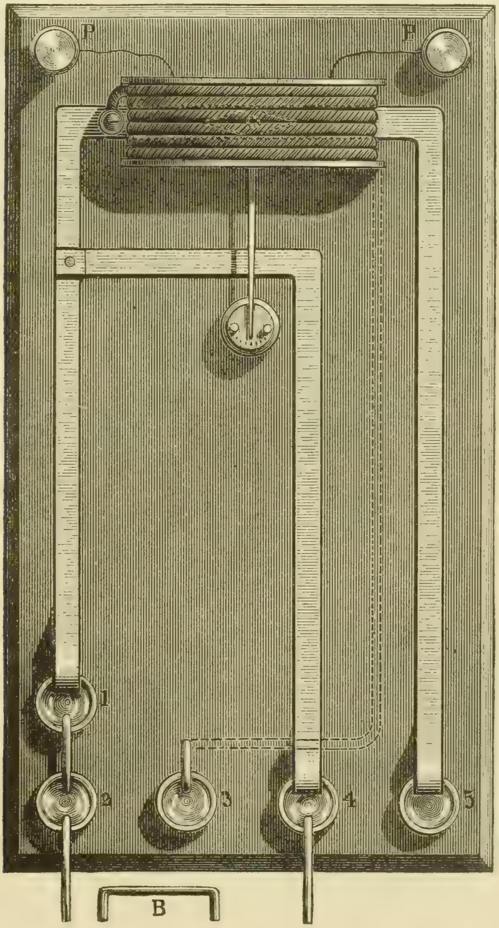

Fig. 515.

by connecting at terminals 2 and 4, which throws in the transverse strap in front of the needle. Bent bars like that shown at B are used to short circuit the galvanometer when required. The extra mercury cup, 1, allows the galvanometer circuit to be opened by the removal of the bent bar between cups 1 and 2, and this may be accomplished without interrupting the continuity of the main circuit if it has been previously short circuited at the other cups. The effect of the leading wires on the needle may thus be noted and remedied by proper manipulation.

To measure current strength, fig. 516, a current from one or more cells of known electro motive force, E, is sent through the fine wire coil, R, and which, by altering an adjustable resistance, W, which is also in circuit, is made to balance the effect on the needle produced by the large current, B, whose strength is to be measured, which is passing through the thick coil, *r*.

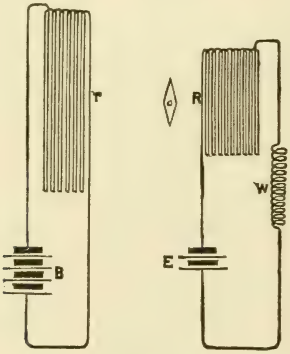

Fig. 516.

The constant value or ratio, Z, of the effects of the two coils on the needle being known, the value of the unknown current, C, may be determined by the simple formula

$$C = Zc$$

where c is the current circulating in the fine wire coil.

For measuring resistances, one end of each coil is connected to the same pole of a battery or dynamo, E, fig. 517; the circuit of the fine wire coil, R, is completed through an adjustable resistance, W, to the other pole of the battery, while the thick coil, r, circuit is completed in a similar manner through the unknown resistance, w. For determining the constant of the instrument a known resistance is substituted for the unknown in the last case. Mr. Cardew has also designed an instrument on the same principle, in which, instead of varying the resistance, the distance between the coils is varied. The fine wire coil is mounted on a slide moved by a screw at right angles to the conductor. On each side of the slide along which the bobbin moves is a pointer moving over a fixed scale of ampères on one side and parts of an ohm on the other. Magnets may be added to both instruments to make them more or less dead beat.

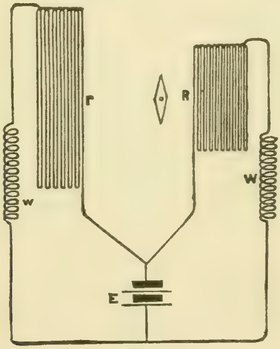

Fig. 517.

ELECTRO DYNAMOMETER.

For measuring currents whose direction is always the same, the apparatus which has been described answers every purpose. In cases, however, where alternating currents, which are employed in some systems of electric lighting, have to be measured, an ordinary galvanometer would give no indications; in such cases an electro dynamometer must be used, as the deflections given by this instrument are always in the same direction, no matter what currents traverse its coils. The principle of the electro dynamometer is based upon the mutual action of currents, *i. e.*, upon the fact that parallel currents in the same direction attract, and in opposite directions repel, one another.

Fig. 518 shows how the principle is applied. A B C D is a fixed wire rectangle, and *a b c d* a smaller one, suspended within the larger, so that it can turn freely about its axis; the planes of the two are at right angles to each other. Now, if the two rectangles be connected together in the way shown, then a current entering at W_1, and passing out at W_2, will traverse the two, and the current passing from B to C will attract the current passing from *a* to *d*, and will repel the current passing from *c* to *b*. A similar action takes place with reference to the current passing from D to A; consequently the smaller rectangle, under the influence of the forces, will tend to turn about its axis in the direction in which the hands of a watch rotate. If the current enter at W_2, and leave at W_1, then, inasmuch as the directions of all the currents in the wires are reversed, the

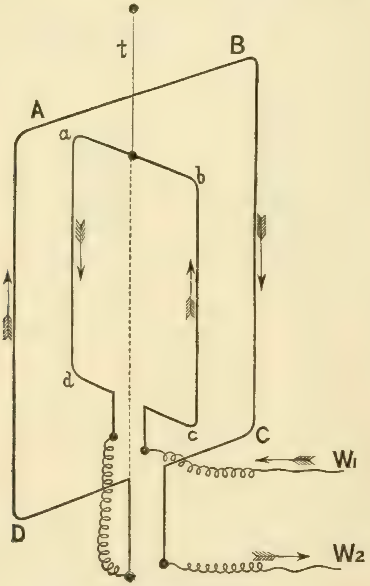

Fig. 518.

small rectangle must still tend to turn in the direction indicated. If one or both of the rectangles consist of several turns of wire, the turning effect for a given current will be proportionally increased.

It might, perhaps, at first be anticipated that the deflections produced by various currents on the electro dynamometer would have about the same relative magnitudes, as regards their number of degrees of divergence, as the deflections on the tangent galvanometer; that is to say, for example, if two currents on the tangent galvanometer gave deflections of 10° and 40° respectively, it might perhaps be imagined that if the smaller current also gave 10° on the electro dynamometer, then the greater would give about 40°. This is not the case, however, for the following reason: In the case of the tangent galvanometer we have a magnetic field formed by a magnet of fixed intensity, and this is not altered by the action of the wire coil; in the case of the electro dynamometer, however, the magnetic field of the movable coil is increased directly as the current is increased; thus if the current passing through the deflecting coil is doubled, then the current passing through the deflected coil is doubled also; consequently we have a doubled current acting upon a magnetic field doubled in intensity, and, therefore, we must have a quadrupled deflective effect: In other words, the deflective force tending to turn the movable coil will vary as the square of the current, and not directly as the current, as in the tangent galvanometer. This value—the square of the current—is precisely the power which is required for many technical calculations, such as the amount of heat or light produced, or the work given out or absorbed by a certain current.

A fine wire electro dynamometer cannot be satisfactorily used for measuring rapidly reversing electro motive force, because of the retardation arising from self induction.

SIEMENS ELECTRO DYNAMOMETER.

A general view of this instrument, which is suitable for measuring current strength, is shown in fig. 519. It consists of a rectangle of wire hung from a spiral spring of platinum wire whose upper end is fixed to a thumb screw provided with a pointer, which can be moved round a graduated dial. The number of degrees to which this pointer points evidently indicates the amount of torsion given to the spiral spring. To the rectangle also is fixed a pointer, the end of which just laps over

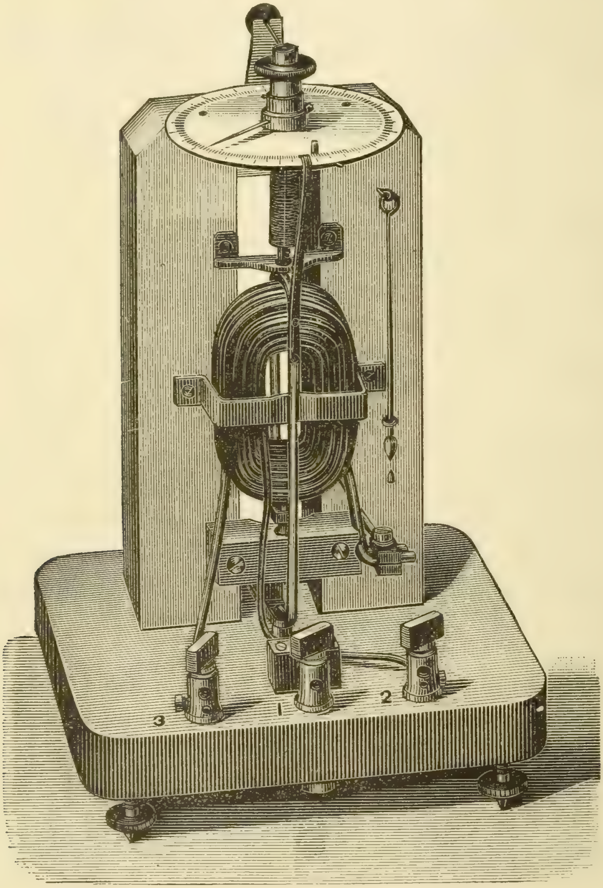

Fig. 519.

the edge of the graduated dial. The rectangle encircles a coil consisting of several turns of thick, and a large number of turns of thin wire; the two ends of the thick wire are connected to terminals 1 and 2, and the two ends of the thin wire to terminals 1 and 3. Connection is made between the rectangle and the wire coils by mercury cups, into which dip the ends of the wire forming the rectangle. The base board has three levelling screws; the level consists simply of a small pointed weight hung at the end of a rod (seen on the right of the figure), the pointed end hangs exactly over a fixed point when the instrument is level.

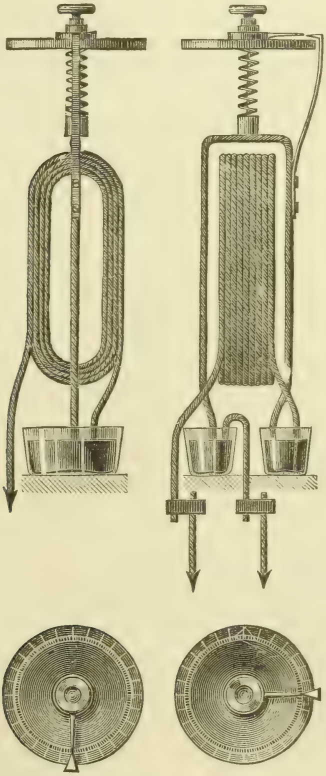

Fig. 520.

The detail of these connections are shown in fig. 520. One of the advantages of this apparatus is that the action of terrestrial magnetism on a single convolution is so slight that it may be neglected, and the instrument does not, therefore, require to be set to the magnetic meridian. The method of using the Siemens electro dynamometer is as follows: The wires leading the current whose strength is to be determined are connected to terminals 1 and 2, or 1 and 3, according as a strong or weak current has to be measured. The current deflects the rectangle; the thumb screw is now turned in the reverse direction to that in which the rectangle has turned, and torsion being thereby put on the spiral spring, the rectangle is forcibly brought back toward its normal position, that is, at right angle to the coils, or to the position at which the pointer attached to the rectangle stands at zero on the scale. The number of degrees of torsion given to the spiral spring being then read off, the strength of the current is found by reference to a table supplied with each instrument. The method of constructing this table is described on page 787.

SIEMENS POTENTIAL GALVANOMETER.

Fig. 521 represents a form of torsion galvanometer devised by Siemens for the measurement of electro motive forces. Although not suitable for measuring rapidly reversing currents, it is the companion instrument to the electro dynamometer just described. It consists of a tuning fork shaped magnet or needle, suspended between two rectangular bobbins wound with fine wire, so placed that their longest sides are vertical. Two brass columns carry the glass top or cover, which has an etched graduation. The columns are connected by a cross piece, in the middle of which is a short brass tube which passes through a hole in the centre of the cover. Passing through the tube is a cocoon fibre on which the magnet hangs; the end of the fibre is wound round a small shaft with a milled head, by means of which the magnet can be raised or lowered. About the tube turns a brass bushing carrying a horizontal indicator, which moves in under the graduations on the cover. On this bushing, which may be turned by means of a brass head from the outside, hangs a fine spring, the other end of which is fastened to the magnet. The cocoon fibre on which the magnet is suspended passes through the centre of the torsion spring and is so adjusted that the bell magnet hangs between the coils. On the upper end of the magnet a little arm is fastened. This latter is twice bent, and is

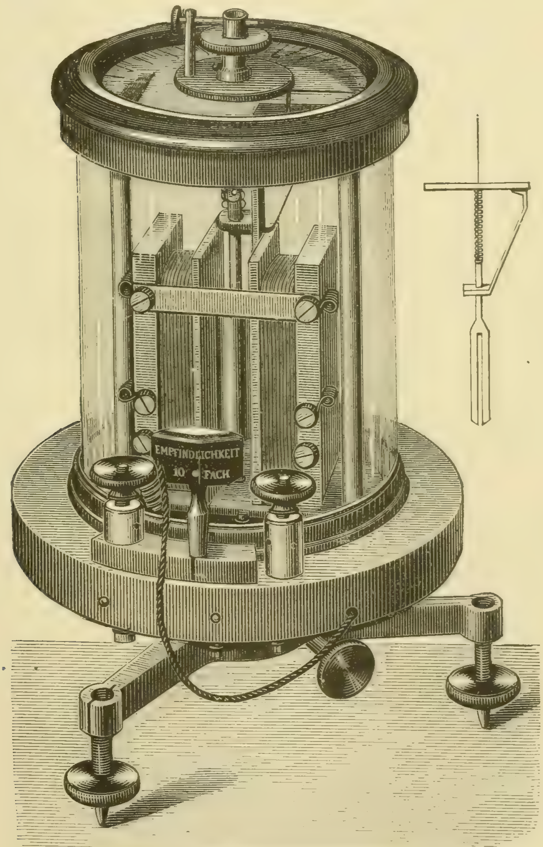

Fig. 521.

finally continued in a short vertical piece which moves under the graduated plate and carries a blackened point directed inward. The index passes through a hole in a fixed plate, which limits its motion. The instrument is so placed that the index point coincides accurately with zero on the graduated plate. When the pointer is deflected by the passage of a current it is brought back to zero, as in the case of the electro dynamometer, by turning the bushing to which the spiral spring is attached; but in the present case the angles of torsion are proportionate simply to the current strength itself, because the magnet does not change its intensity with the current. The torsion of the spring is measured on the graduated glass cover, and a table supplied with each instrument gives the relation between the degrees of graduation and the electro motive forces. The instrument measures differences of potential ranging from $\frac{1}{100}$ of a volt to 100 volts, a shunt, which is inserted by the removal of a plug, shown in the figure, being used for all electro motive forces over 10 volts. In using this instrument the resistance of the leads is almost immaterial, at least within the usual requirements.

Owing to the difficulties arising from the heating of the coils in ordinary potential galvanometers, the measurement of electro motive forces above 200 volts can be more accurately made with some form of condenser or electrometer. Condensers for such work should be specially well insulated, as it is found in practice that ordinary condensers cannot be safely used for measuring high potential machine currents. The electrometers of Sir William Thomson are open also to a similar objection, but they can be easily modified to suit the new conditions, and some have already been successfully constructed for this purpose.

AYRTON AND PERRY'S CYLINDER SPRING ELECTROMETER.

This is a modification of the Thomson electrometer, designed to be conveniently portable and sufficiently sensitive to measure the high electro motive forces for which it is intended without being over delicate. It is constructed as follows: Two vertical is broken, contact with the next is made. Continuity of the circuit is thus preserved.

WESTON'S LABORATORY RHEOSTAT.

Fig. 524 shows a form of heavy current rheostat, designed by Mr. Edward Weston for use in laboratories and electrical workshops. It consists of thirty wooden sticks, each about three feet long by one inch square, mounted on a circular wooden base, with a corresponding circular cover or top. Each stick is notched or cut at right angles to its length at about every half inch. In these notches, as shown in the figure, German silver wire of suitable diameter is wound double, after the method usually adopted in standard resistance coils, called differential winding. Galvanometer needles in its vicinity are not, therefore, affected by currents circulating in this rheostat. Thirty brass contact plates, corresponding to the thirty sticks, form a circle about the top and close to the edge of the cover. A movable arm carrying a platinum faced spring slightly narrower than the contact plates, moves over the latter. The width of the spring prevents contact with one plate being broken before contact with the next is made. The resistance of the wire on each stick varies from one tenth of an ohm to 5 ohms or more. In some of these rheostats all the sticks are one tenth of an ohm each, and in others they are all one ohm each. The wires are connected to the contact strips in the manner shown by the sectional drawing, fig. 525, which also shows the arrangement of the sticks. The

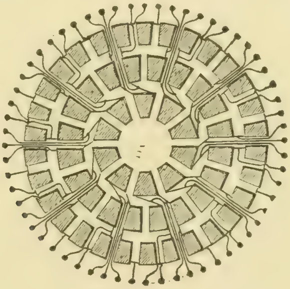

Fig. 525.

position of the sticks permits of the free circulation of air, and as very large wire may be used, currents of six or eight ampères can be carried by this rheostat without causing serious heating.

WESTON'S RIBBON RHEOSTAT.

This is a very durable and serviceable rheostat in which the resistances are of German silver ribbons, as shown in plan in fig. 526 and in section in fig. 527. It consists of a heavy upright frame, enclosing a wide board, upon which the devices supporting the ribbons are mounted. In a line along the upper edge of the board, and as close together as practicable, brackets of cast brass, *f*, are screwed, the upper portions of which act as contact surfaces. Along the lower end of the board and corresponding in number and position to the upper castings a second row of brackets, G, are clamped. Stout spiral springs, S, are made fast to the opposite ends of the bars of these brackets, and their free ends attached to insulated pins, *g*. The conductor consists of a long, flat strip or ribbon, A, of German silver. One end is secured to the bar of the first upper bracket, and is then carried alternately under the pins attached to the springs and over the upper castings in regular order, until all the upper and lower brackets are connected. The first one of the series of upper brackets is connected by a thick metal strip with a binding post, P, and on the opposite side of the board are arranged brackets, contacts, and a ribbon, exactly corresponding to that described. Along the upper edge of the frame is a metal guide, D, upon which a metal block, B, slides. Rods depending from either side of the block carry brushes, C, which run over the contact surfaces, and a binding post, P′, is set in the block. Along the upper surface of the metal guide is a scale, shown in plan in fig. 528, by means of which the resistances corresponding to different positions of the block are ascertained. If one end of a circuit be connected to the binding post, P′, on the block, and the other end with either of the end binding posts, P P, as much resistance will be introduced into the

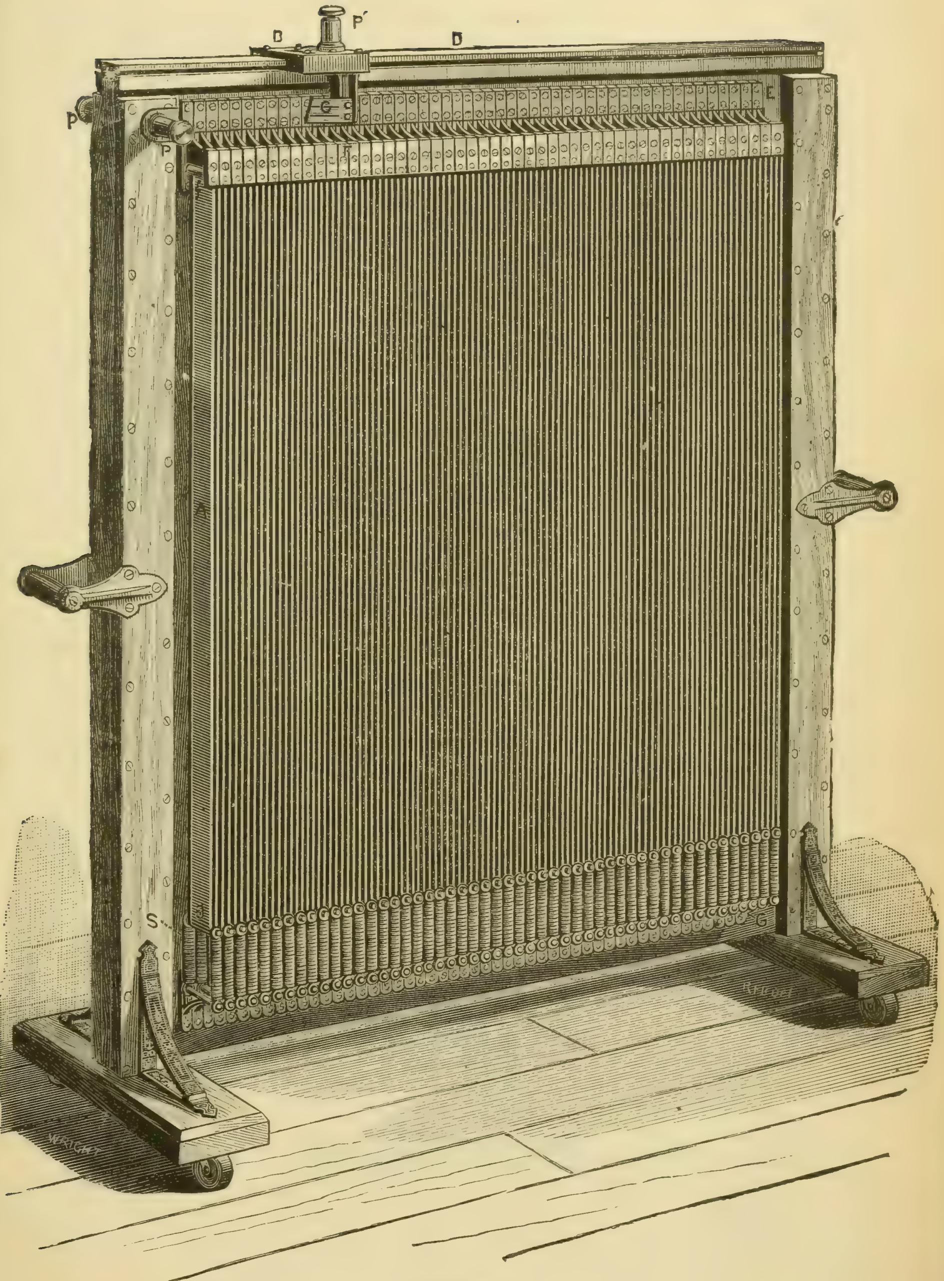

Fig. 526.

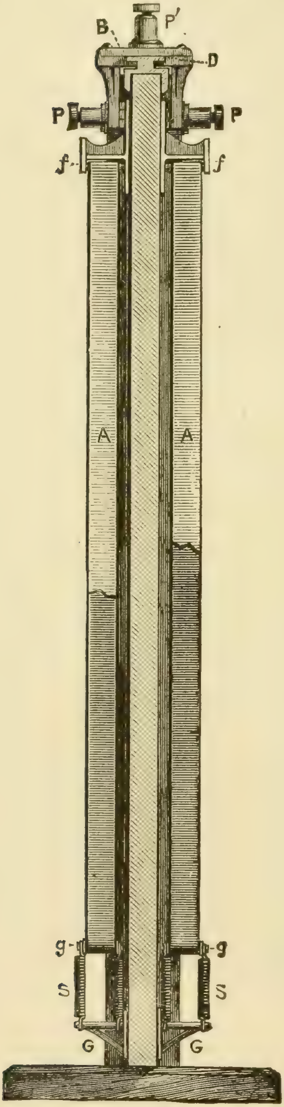

Fig. 527.

circuit as lies between the end binding post and the bracket in contact with the brush, C, on that side. If, however, the circuit be connected to the two end binding posts, P P, twice as much resistance will be introduced in the circuit, for the path of the current will then be from one end binding post through the ribbon to the brush on that side, then through the block and out of the brush on the other side, back through the ribbon to the other end binding post. Again, by attaching one end of the circuit to both end binding posts, and the other end to the block binding post, the ribbons are connected in multiple circuit and the resistance for a given position of the block will be one half what it was in the first case, or one quarter of the resistance in the second case. The large surface of metal exposed to radiation enables this rheostat to carry very large currents without its temperature being greatly raised. On the other hand, should it become heated sufficiently to cause considerable expansion, the springs will take up the slack of the ribbon and prevent short circuiting.

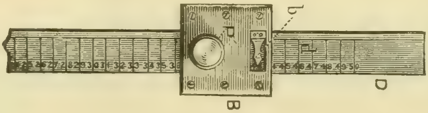

Fig. 528.

WESTON'S FIELD EXPLORER.

Mr. Edward Weston has devised a very ingenious instrument for investigating the distribution of magnetism in the field magnets of dynamo electric machines. Fig. 529 shows the instrument ready for use. It consists of a miniature Weston armature, the shaft of which is extended on the commutator side for several inches, and passes through a wooden handle, within which its bearings are placed. The opposite end of the shaft is attached to a convenient length of Stowe's flexible shafting (such as is used in dental apparatus), which allows of the armature being moved about as desired. The other end of this flexible shaft passes through a bearing, so arranged that it may be attached to any suitable support, and carries a small pulley. By means of this pulley a constant velocity of rotation is given to the armature, which is then brought within the field of force

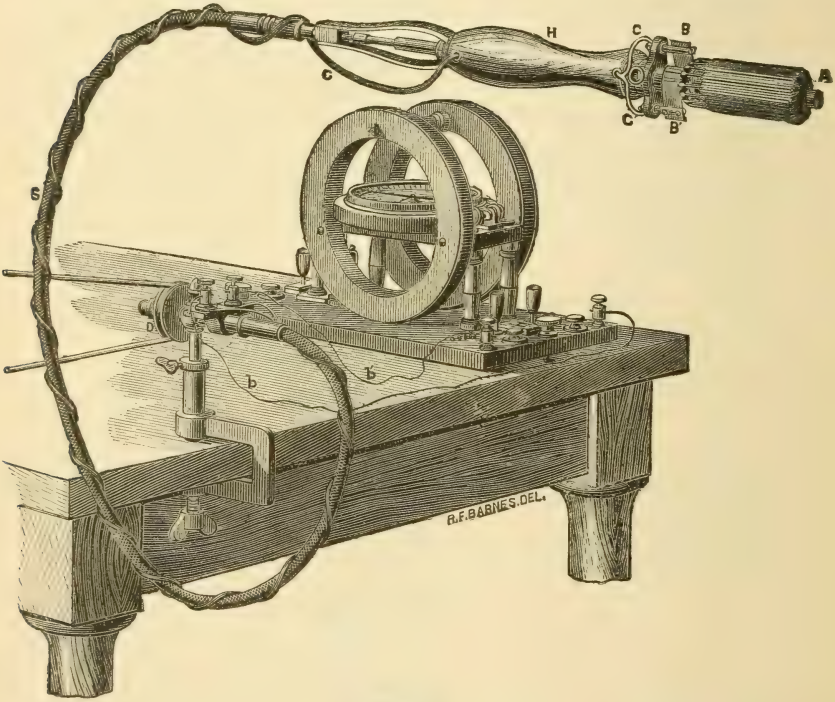

Fig. 529.

to be investigated. The armature is connected with the wires leading to a galvanometer, which indicates the intensity of the current flowing. Now the strength of the current induced in an armature revolving at given speed being directly proportional to the number of lines of force which it cuts, it is evident that the current which flows through the galvanometer will be a direct measure of the strength of the magnetic field at the point in which the armature rotates. By means of this instrument the intensity throughout the field of force of any dynamo electric machine may be readily plotted.

MAGNETO TESTING BELLS.

Magneto call bells, such as are used in connection with telephone systems, are sometimes employed for testing the continuity, and, in a rough way, the insulation of lighting circuits during construction. Their portability and simplicity render them serviceable to linemen and others, although they do not in any degree take the place of the galvanometer and rheostat. When the cranks are turned at about 200 revolutions per minute these bells will ring through a resistance varying from 1,000 to 10,000 ohms, according to size and construction. They will, therefore, indicate leaks of such, or less, resistance, but do not measure them. By moving these magnetos from place to place, or by opening the circuit at different points, grounds may be located.

Fig. 530 shows the internal arrangement of a form of magneto and bell designed specially for testing lighting circuits by C. J. H. Woodbury. It consists of a Siemens armature of 400 ohms resistance in the field of five horseshoe magnets. The armature is revolved from a driving wheel, provided with a hand crank, by means of a belt which passes around an adjustable guide pulley. There is no commutator, and the alternating current passes through a sensitive polarized electro magnet which actuates an armature vibrating between two gong bells. Two flexible conductors, with spring clips for making connections, are wound on reels contained in the enclosing box. At 200 revolutions of the crank per minute this magneto will generate an electro motive force of about seven volts, and the bell will ring through 7,000 ohms external resistance. The whole is contained in a case eight inches long and four wide, and weighs three pounds.

MEASUREMENT OF CURRENT STRENGTH AND ELECTRO MOTIVE FORCE AND CALIBRATION OF APPARATUS.

If the deflections of the needle of a galvanometer are in direct proportion to the strength of the current by which they are produced, and a current of known strength, C, deflects the needle through an angle of $d°$, the value of the current, which would

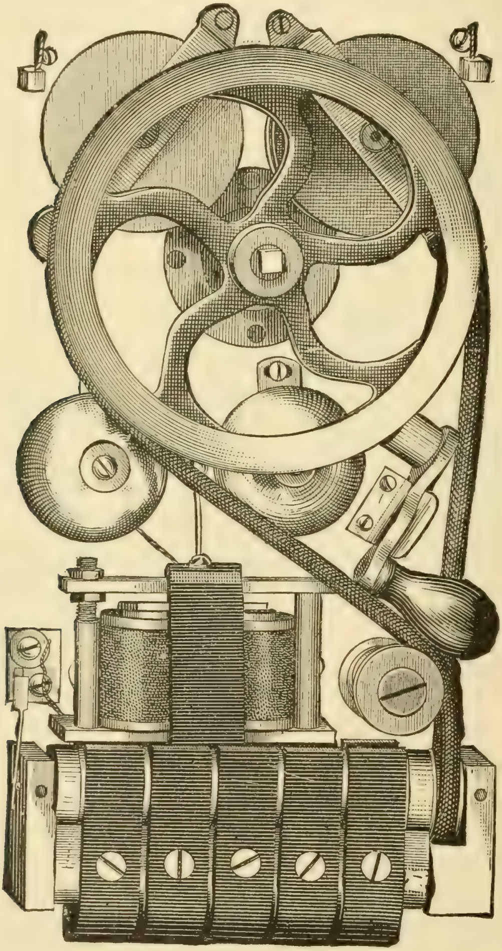

Fig. 530.

produce a deflection of 1°, will be represented by the quotient of $C \div d$. This value is called the constant of the instrument. When each division of the scale of the galvanometer has been multiplied by the constant, the value in ampères of each division will have been calculated, and if the corresponding products be marked upon the scale, or otherwise conveniently tabulated, the instrument is said to have been calibrated. Voltmeters, by substituting electro motive force for current, are calibrated in the same manner. The constant of an ammeter may be determined by any of the methods employed for measuring current strength, and the measurement of current strength is always involved in the operation. Similarly the measurement of electro motive force is the first requisite for calibrating a voltmeter.

There are six general methods by which the strength of a current can be measured, viz.: I. By a calibrated galvanometer. II. By calculation from electro motive force and resistance. III. By electrolysis. IV. By the chemical action in a voltaic cell. V. By its heating effects. VI. By calculation from the dimensions of a tangent galvanometer.

The first two methods, which are also employed in measuring electro motive force, are ordinarily used on account of the facility with which they can be applied. The third, fourth and fifth are employed where accurate results are required, and the sixth method is occasionally resorted to in physical laboratories where dimensions and conditions can be accurately ascertained, chiefly as a check on the others. These six methods of measuring current strength, together with the first two for measuring electro motive forces, as applicable to the determination of galvanometer constants, will be described in the order in which they have been stated.

I. BY COMPARISON WITH A STANDARD GALVANOMETER.

Connect together in simple circuit (fig. 531) a calibrated galvanometer, G_1, a battery or dynamo electric machine, E, and the galvanometer, G_2, whose constant is required. Note the strength of current, C, as indicated by the standard galvanometer, and observe the deflection produced in the second galvanometer; calling the latter d, then

$$\text{Constant} = \frac{\text{C}}{}$$

and for a tangent galvanometer

$$\text{Constant} = \frac{\text{C}}{\tan.\ d.}$$

Representing the constant by k, the value, C_1, in ampères of any other deflection d_1 will be

$$C_1 = k\, d_1,$$

and for a tangent galvanometer

$$C_1 = k \tan.\ d_1.$$

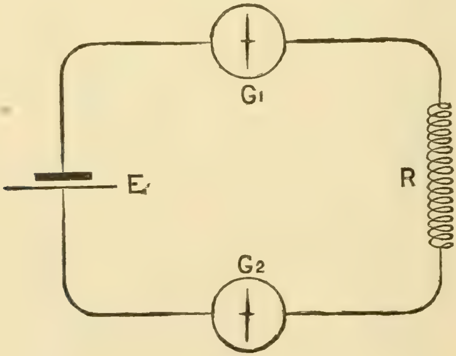

Fig. 531.

An adjustable resistance, R, of which no account is to be taken in the formula, may be placed in the circuit to vary the strength of the current so as to give any convenient deflection of either galvanometer.

This method is employed as follows for measuring electro motive force: When the standard galvanometer has been calibrated in volts, the second galvanometer may be calibrated for electro motive force by the method shown in fig. 532. Connect the terminals of both the standard galvanometer and the galvanometer to be calibrated to two points in a circuit in which a current is flowing—for instance around an incandescent lamp—or to the end of a battery. Note the electro motive force as indicated by the standard galvanometer and also observe the deflection, d, of the second galvanometer. Letting E represent the electro motive force,

$$\text{Constant} = \frac{E}{d},$$

and for a tangent voltmeter

$$\text{Constant} = \frac{E}{\tan.\ a}.$$

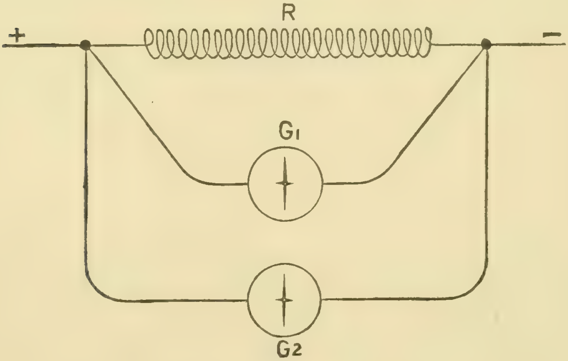

Fig. 532.

If, as before, the constant is represented by k, the value E^1 of any other deflection d_1, in volts, will be

$$E_1 = k\,d_1,$$

and for a tangent voltmeter

$$E_1 = k \tan.\ d_1.$$

In calibrating an instrument by this method it should be remembered that the constant of the standard galvanometer may be more or less altered by removing it from the spot on which it was calibrated. The proximity of iron or of wires carrying currents would be liable to affect its accuracy, and if of the permanent magnetic field class, any variation in the strength of the magnet would have a similar result.

II. BY CALCULATION FROM ELECTRO MOTIVE FORCE AND RESISTANCE.

Insert the galvanometer in a circuit in which the electro motive force and resistance are known or can be measured, and note the deflection, d. If the resistance is R ohms and the electro motive force E volts, the strength in ampères of the current producing the deflection will be

$$C = \frac{E}{R},$$

whence

$$\text{Constant} = \frac{C}{d}.$$

For example, connect the galvanometer with the standard Daniell cell (described on page 773), together with a small adjustable resistance. The electro motive force of the cell may be taken as 1,079 volts. Supposing the galvanometer resistance to be so small as to be disregarded, it is first necessary to determine the internal resistance of the cell; this may be done approximately by noting the deflection, first, d when only the battery resistance, r, is in circuit, and, second, d_1 when an additional resistance, r_1 (say one or two ohms), has been inserted. If the deflections are proportional to the current strength

$$r = \frac{d_1\, r_1}{d - d_1}.$$

Hence, if the inserted resistance is so adjusted that the second deflection, d_1, is equal to $\frac{1}{2}\, d$,

$$r = r_1.$$

The total resistance of the circuit is then $r + r_1$ and

$$C = \frac{1.079}{r + r_1}$$

and

$$\text{Constant} = \frac{C}{d_1}$$

With the battery resistance only in circuit

$$C = \frac{1.079}{r.}$$

If the galvanometer has an appreciable resistance it should be subtracted from the above values for r, and added to the total resistance of the circuit in the formulas.

The constant of any galvanometer whose deflections are proportional to the currents producing them is equal to

$$E \frac{d - d_1}{d \ d_1,}$$

where E is the electro motive force and d, d_1, the deflection produced by this electro motive force through a small and large resistance respectively. For a tangent galvanometer the tangents of the angles of deflection would be substituted for the deflection, thus:

$$\text{Constant} = E \frac{\tan. d - \tan. d_1}{\tan. d \times \tan. d_1.}$$

The Ayrton and Perry commutator ammeter is provided with a resistance coil of one ohm for its calibration by the above method. It is thrown in circuit by the removal of a small plug in the base of the instrument. Their commutator voltmeter is also provided with a similar coil equal to the resistance of the instrument when in parallel circuit.

To calibrate the ammeter, the commutator is turned to series, and a current sent through the instrument by a cell of known electro motive force, E, but of unknown resistance, producing, say, a deflection, d; the plug is now taken out, and a second deflection, d_1, obtained. From this it can easily be shown that a current of

$$10\,\frac{d-d_1}{d\,d_1}\,E \text{ ampères}$$

will produce 10° deflection when the commutator is in series, or 1° deflection when the commutator is to parallel.

To calibrate the voltmeter, the commutator is turned to parallel, and a current sent through the instrument, and the deflection produced when the plug is in and out noted as before. Then

$$10\,\frac{d-d_1}{d\,d_1}\,E \text{ volts}$$

between the terminals of the instrument will produce a deflection of 10° when the commutator is parallel, or 1° when to series.

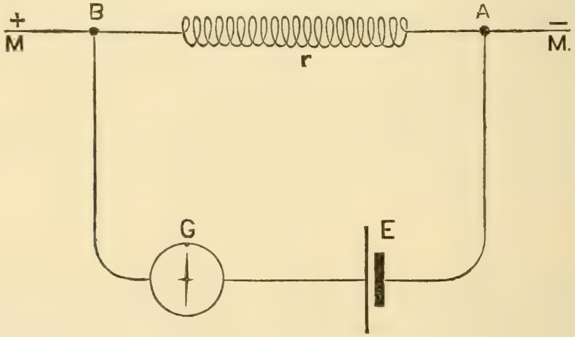

Fig. 533.

A second method of determining current strength from electro motive force and resistance, based on the principle of balancing opposed electro motive forces, is as follows: A wire, M M (fig. 533), whose resistance, r, between the points, A B, can be measured, is carrying the current, C, whose strength is required. Between the two points, A and B, and in derivation with r, a second circuit containing the galvanometer, G, and the standard

Daniell cell E is placed. The electro motive force of the standard cell is opposed to the difference of potential between the points A and B. If these points are adjusted, by being moved closer together or further apart, until there is a suitable resistance between them, the galvanometer needle will stand at zero. When this condition is established, the difference of potential between the points A B is equal to the electro motive force of the cell, and therefore

$$C\, r = 1.079$$

whence

$$C = \frac{1.079}{r.}$$

The galvanometer may now be inserted in the circuit M M, its deflection d noted, and the constant calculated in the usual manner, viz.:

$$k = \frac{C}{d.}$$

By a slight extension of the above method, the current flowing in a wire may be accurately measured, when the potential between the two points to which the galvanometer and standard cell are connected differs by only a fraction of a volt. In fig. 534, A B is the wire carrying the current, C, to be measured. The standard cell, E, is closed through a high resistance, $r\ r_1$ (of, say, 1000 ohms). One end of the battery is also connected to the point a in the large wire, and at another point, b, a connection is made with the resistance, $r\ r_1$. This latter connection is moved along $r\ r_1$, until the needle of the galvanometer stands at zero.

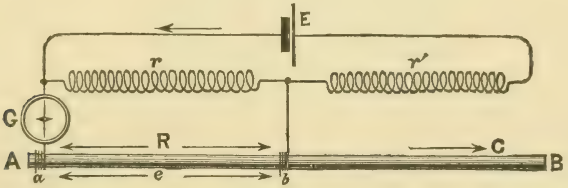

Fig. 534.

If, now, the electro motive force between *a* and *b* is represented by *e* the following ratio exists.

$$e : \mathrm{E} = r : r + r_1$$

$$\therefore e = \frac{\mathrm{E}\, r}{r + r_1},$$

and if the resistance between *a* and *b* is R ohms,

$$\mathrm{C} = \frac{\mathrm{E}\, r}{\mathrm{R}\,(r + r_1)}.$$

Galvanometers may be similarly calibrated for electro motive force by calculation from current strength and resistance. In fig. 535 the strength of the current C flowing in wire M M is measured by the galvanometer G_1. To the points A B in this wire the voltmeter G_2 to be calibrated is connected, and its deflection, *d*, noted. The resistance of the conductor (wire or lamp) between the points A B is *r*; therefore

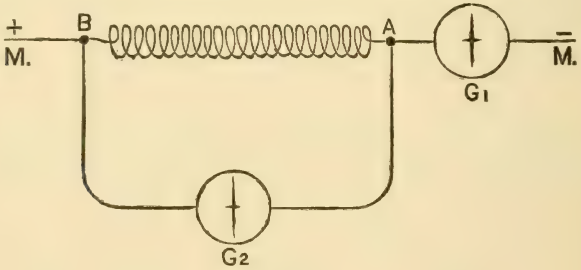

Fig. 535.

$$\mathrm{E} = \mathrm{C}\, r$$

and

$$k = \frac{\mathrm{E}}{d}.$$

III.—BY ELECTROLYSIS.

The copper voltameter, fig. 536, consists of a vessel containing a saturated solution of sulphate of copper, in which two thin sheets of pure copper, A and K, are immersed. A current passing through the cell from + to — electrolizes the sulphate of copper solution, and the anode, A, is slowly dissolved, while the kathode K receives an equal quantity of copper as a deposit upon its surface. A zinc voltameter consists of similar plates of zinc immersed in a saturated solution of sulphate of zinc. When a current is passed through the voltameter the anode dissolves and the kathode gains an equal quantity of zinc. The weight of metal dissolved in any voltameter is proportional to the quantity of current and to the electro chemical equivalent of the metal employed (see page 786).

To calibrate a galvanometer by electrolysis it is connected in series with a voltameter and battery or dynamo adjusted to give a convenient deflection. If the electro motive force is at all inconstant it is best to have also a rheostat in circuit in order to keep the deflection constant. The plates of the voltameter having been carefully cleaned and weighed, are then placed in the cell and the circuit closed. The time during which the current flows should be accurately noted, as also the galvanometer deflection, which latter should be kept constant by means of the rheostat. The plates are then removed, carefully washed and dried with alcohol, after which they are again accurately weighed and the loss in weight of the anode and gain in weight of the kathode computed. The gain and loss ought to be equal, but

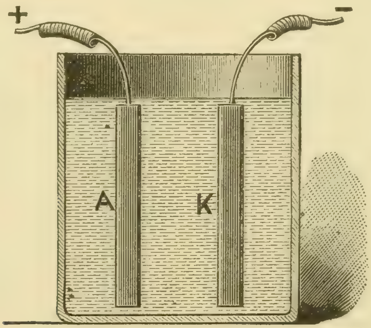

Fig. 536.

this is not always the case, owing chiefly to stripping of the kathode. The loss in weight of the anode is therefore generally taken as the weight of metal transferred.

The strength of the current is calculated from the formula

$$C = \frac{W}{a\ t},$$

where W = weight in grammes of metal dissolved;
a = electro chemical equivalent of the metal; and
t = time in seconds during which the current flowed.

The deflection, d, of the galvanometer having been observed,

$$k = \frac{c}{d}.$$

The value, *a*, for various metals is given in the table on page 784. Its value for copper, for example, is ·0003276, and for zinc plates *a* would be equal to ·0003407. The zinc voltameter will give extremely uniform results if electro deposited zinc and chemically pure zinc sulphate are used. It is best to boil the latter with chips of metallic zinc before using.

When water is electrolized the volume of the gases liberated is proportional to the current strength. The water voltameter consists primarily of two platinum electrodes immersed in a vessel of water to which a small quantity of sulphuric or hydrochloric acid has been added to reduce its resistance. Fig. 537 shows the method of arranging the water voltameter for measuring current strength, where E represents the battery or current generator; R, the variable resistance for adjusting the current; G, the galvanometer to be calibrated; V, the voltameter placed in W^1; W^1, the water tank kept at one temperature; P, the bent pipe for conducting mixed gases, H_2 and O, over to C; C, the cubic centimetre vessel, say 250 or 1,000; W^2, another water tank kept at one temperature; t^1, t^2, two centigrade thermometers; B, the standard barometer.

The mixed gases are collected by displacement in C, a vessel of known capacity. The time required to fill the vessel being very carefully noted, the temperature observed, as well as the barometer in millimetres, by a combination of Gay Lussac's and Boyle's laws,

$$C = \frac{V + 273 + P}{0{\cdot}1764 + t\,(273 + T) + 760},$$

where C = current in ampères; V, volume of gas given off in C; P, height of barometer; t, time in seconds; T, temperature centigrade; 0.1764, volume of mixed gas, H_2 and O, given off

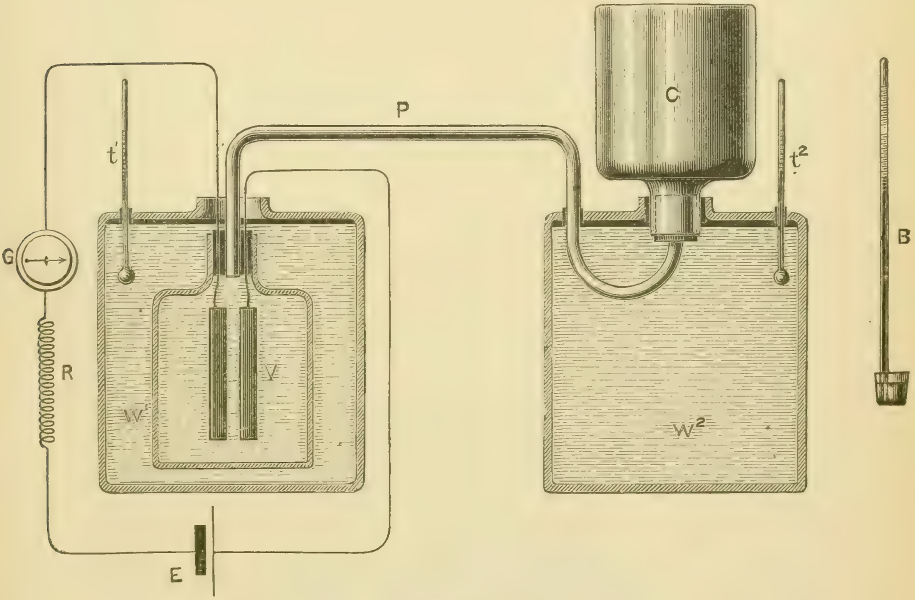

Fig. 537.

per second by **1** ampère; 273, constant for variation of volume of a gas with temperature; 760, standard barometric pressure.

For measuring heavy currents the voltameter electrodes must be large and not very far apart. Having noted the deflection, *d*, of the galvanometer, its constant will be

$$k = \frac{c}{d}.$$

IV.—BY THE CHEMICAL ACTION IN A VOLTAIC CELL.

This method, which is an extremely accurate one in careful hands, only requires a Daniell cell. For calibrating low resistance galvanometers the cell should be large, so as to have but little resistance in order to give a considerable current. A good form of cell has an oblong, flat sided porous cup containing a broad, thin sheet of pure zinc in a nearly saturated solution of zinc sulphate. This plate should be perfectly amalgamated, great care being taken to remove all superfluous mercury, as the loss of a small globule, after weighing, would materially affect the results. The outer jar containing the porous cell is filled with a saturated solution of pure copper sulphate, in which are immersed two large plates of copper, one on each side of the porous cell and very close to it, but not in contact. The two copper plates, which should be well cleaned, are connected together and form the negative electrode. The porous cell should be soft and perfectly clean, to insure which it is well to soak it in pure water for some time before using. The zinc plate, after having been carefully weighed, is placed in the porous cell and the galvanometer to be calibrated is connected to the battery. As the electro motive force of the cell gradually rises a little and then falls off, it is best to have a small sliding wire resistance in circuit in order to keep the deflection constant. The exact time of closing the circuit should be noted, as also the time of opening; one to two hours will usually suffice to reduce an accurately weighable quantity of zinc. The deflection, d, having been kept uniform by means of the wire resistance, at the end of the time, t, the zinc plate is removed, quickly and carefully washed, dried and weighed. The loss in weight, W, in grammes having been computed, the strength of the current is equal to

$$C = \frac{W}{a\,t},$$

where a is the electro chemical equivalent of zinc and is equal to 0·340725 milligrammes per ampère. For the galvanometer constant

$$k = \frac{c}{d}.$$

V.—BY ITS HEATING EFFECT.

The number of gramme degree centigrade units of heat developed by a current is proportional to the square of the strength of the current, to the time which it lasts, and to the resistance of the conductor. The number of heat units developed by a current in any portion of a conductor is proportional to the resistance of that portion. When the current strength, resistance and time are known the quantity of heat may be calculated from the formula

$$H = C^2 R t \times 0{\cdot}2405 \text{ heat units} \ldots . (1).$$

The heat generated by a current can be measured directly by means of a calorimeter. One form of this instrument, shown in fig. 538, consists of a glass vessel containing alcohol, in which a thin wire of known resistance is submerged, its ends being connected to heavy conducting wires. A delicate thermometer also dips into the alcohol. When a current is sent through the calorimeter wire for t seconds it becomes heated, imparts heat to the

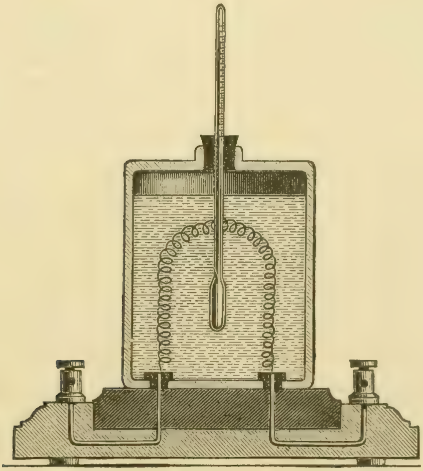

Fig. 538.

alcohol and raises the temperature of the latter from T° to T_1° centigrade. If W represents the weight in grammes of the alcohol, and s its specific heat, the quantity of heat developed in the calorimeter will be

$$H = \frac{W\,s \times (T_1 - T)}{t} \text{ heat units....(2).}$$

Combining formulas 1 and 2, by obvious transformations:

$$C = \sqrt{\frac{W\,s \times (T_1 - T)}{R\,t \times 0{\cdot}2405.}} \text{ ampères.....(3).}$$

That is to say, having measured the heat imparted to the calorimeter by a current of unknown strength, C, and knowing the resistance, R, of the thin wire, the value of C in ampères may be calculated by formula 3.

It is obvious that the containing vessel, which is originally at the temperature of the alcohol, shares its increase of temperature, and in accurate experiment this must be allowed for. If the weight of the vessel be w and its specific heat s_1, $w\,s_1$ is equal to the weight of water which would absorb the same quantity of heat as the vessel. This is said to be the water equivalent of the vessel, and its value should be added to W in formula 3. The expression accordingly becomes

$$C = \sqrt{\frac{(W\,s + w\,s_1)\,(T_1 - T)}{R\,t \times 0{\cdot}2405.}} \text{ ampères..(4).}$$

In accurate experiments it is necessary also to allow for the heat absorbed by the calorimeter wire, and by the glass and mercury of the thermometer, by introducing into the equation their values reduced on the same principle.

In order to allow for the loss of heat due to radiation, a preliminary experiment is made, the only object of which is to ascertain approximately the increase of temperature of the alcohol. If this increase be 10°, for example, the temperature of the calorimeter is reduced by half this number—that is to say, 5° below the temperature of the atmosphere—and the test is then carried out in the ordinary manner. By this method of compensation the water receives as much heat from the atmosphere during the first part of the test as it loses by radiation during the second part.

For measuring very heavy currents and calibrating high range galvanometers, a modified form of calorimeter may be employed. For this purpose the containing vessel is made of thin sheet zinc, cylindrical in form, and with a capacity of, say, 50 to 100 pounds of water, according to the strength of the current to be measured. The vessel is filled with distilled water, which has a much lower conducting power than impure water, and a German silver wire 10 to 20 feet long, in the form of a large spiral, is suspended therein. The wire is of such a diameter as to have a resistance of, say, half an ohm, but the best resistance to employ is determined by the size of the calorimeter and the strength of the current. The resistance of the wire should be the same in the water as out, but it ought to be measured both in and out, in order to be sure that there is no conduction of current through the water. The specific heat of water is unity at 0° cent., and *s* is therefore generally omitted from formula 4 when the water calorimeter is employed. When great accuracy is sought, its specific heat at the average temperature to which the water is raised may be taken, and the resistance, R, of the wire should also be measured at this temperature. The water must be frequently stirred, in order that its temperature may be uniform throughout. The same corrections are applied as in the case of the alcohol calorimeter, and the following values may be taken:

Specific heat of average German silver........ = ·0927
Specific heat of zinc........................ = ·0944

The galvanometer to be calibrated, having been kept in circuit during the test, and its deflection observed, its constant is calculated in the usual manner:

$$k = \frac{c}{d.}$$

VI.—FROM DIMENSIONS OF TANGENT GALVANOMETER.

If the radius of the ring of a tangent galvanometer is represented by r, and a current of unknown strength, C, produces a deflection of d degrees, the value of C may be calculated directly from the equation,

$$C = H \times tan.\ d \times 1{\cdot}59151\ r \text{ ampères,}$$

where H is the value in absolute units of the earth's magnetic force.

If the ring is composed of n turns of wire, the expression becomes,

$$C = H \times tan.\ d \times \frac{1{\cdot}59151\ r}{n} \text{ ampères,}$$

r in this case being the mean radius.

The value of H at various places can be ascertained by reference to a magnetic chart. It is best, however, to determine its value at the time the test is made, for the spot on which the galvanometer stands, as it is influenced by local causes.

SIMILAR METHOD WITH ANY GALVANOMETER.

The current to be measured is passed through a long, straight copper wire, stretched vertically. A small compass needle is arranged at a distance equal to a centimetres from the vertical wire; the axis of the wire and the centre of the needle are in the same magnetic meridian. Under the influence of the current of strength, C, the needle deviates to the angle d degrees. If a has only a length of a few centimetres, and the wire is more than a metre long above and below the horizontal plane which contains the magnetized needle, the vertical wire may be considered as infinitely long, and

$$C = H \times tan.\ d \times 5\ a,$$

where H is the horizontal intensity of the terrestrial magnetism.

By making the coefficient of $tan.\ d$ equal to unity, by placing the needle at $\frac{1}{5\,H}$ centimetres from the wire,

$$C = tan.\ d.$$

The galvanometer to be calibrated would, of course, have to be placed in some portion of the circuit of which the vertical wire formed a part.

MEASUREMENT OF ELECTRO MOTIVE FORCE BY CONDENSER METHOD.

When a voltaic cell is closed through a resistance, its electro motive force is not the same at its terminals as it is when open. This change is due to two causes: the polarization of the electrodes, and the change in the ratio of the resistance of the cell to the external resistance. The internal resistance of the cell is itself also subject to change. By comparing the throw of the needle of a mirror galvanometer when a condenser charged by a known electro motive force is discharged through it, with the throw produced by the same condenser when charged by an unknown electro motive force, the value of the latter may be calculated. This method, of which fig. 539 is a diagram of connections, avoids the difficulties referred to, as the resistance of a condenser is practically infinite. Referring to the diagram, K is a discharge key, C a condenser, G a mirror galvanometer, and E a battery of known electro motive force. To make the test,

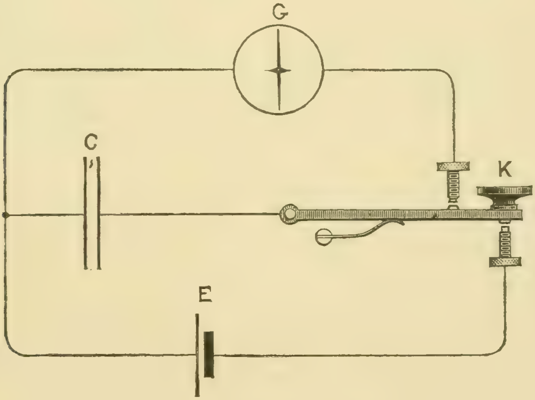

Fig. 539.

close K for, say, 10 seconds, then discharge the condenser and note the deflection d of the galvanometer. Now remove E, and in its place connect the two points whose difference of potential E_1 is to be ascertained. Charge for 10 seconds and discharge as before, calling the last deflection d_1. Then

$$E_1 = E \frac{d}{d_1}.$$

If d and d_1 differ very materially the following correction for resistance of air should be applied to both, viz.: after observing the throw, note the point which the spot of light reaches in its next return. The correction to be added to the first deflection is $\frac{1}{4}$ of the difference between the two readings. Obviously the two points referred to may be the ends of a lamp or other resistance, the poles of a battery or the terminals of a dynamo electric machine. As most accurate results are obtained by comparing electro motive forces which do not differ widely, when it is required to measure high electro motive forces it is best to employ a number of cells for comparison. A few of these can be compared with a standard cell, and they in turn with others, until the total electro motive force of the cells used is ascertained.

Calibration of Electro Dynamometers.

Electro dynamometers may be calibrated for current and electro motive force by any of the preceding methods. In all of the foregoing tests the dynamometer would be simply substituted for the galvanometer, and the torsion ($d°$) required to bring its pointer to zero observed. The constant is then determined in the usual manner

ELECTRIC LIGHT MEASUREMENT.

When a dynamo electric machine is driven by a steam engine or other motive power, and thereby generates a current which is made to supply a circuit of arc or incandescent lamps, the energy applied to the armature pulley appears as heat in the machine, conducting wires and lamps. A portion of the energy absorbed by the dynamo is expended in overcoming the friction of the armature and in generating wasteful Foucault currents in the armature core and pole pieces of the field magnets; the remainder of the total energy absorbed by the dynamo is converted into electrical energy, which is expended in overcoming the electrical resistance of the circuit, and this part is distributed in direct proportion to their respective resistances, between the dynamo, conducting wires and lamps. The amount of energy dissipated in any part of the circuit may be computed by the following formulas:

If the energy actually applied to the pulley of a dynamo electric machine, as measured by a dynamometer, is P horse power, and it requires p horse power to drive the armature at the same speed on open circuit, in order to overcome friction of bearings and resistance of air, the energy, W, expended in turning the armature in the magnetic field (assuming the friction to be the same in both cases) will be

$$W = P - p \text{ horse power} \ldots\ldots\ldots\ldots (1).$$

The total electrical energy developed per second, by a dynamo electric machine, is equal to the product of the difference of potential or electro motive force, E, at its binding posts into the strength of the current, C, in its armature, plus the product of the square of the current into the resistance, r, of the dynamo. Expressed algebraically,

$$\text{Total electrical energy} = \frac{E\,C + C^2\,r}{746} \text{ H. P.} \ldots\ldots (2).$$

It is also equal, therefore, to the square of the strength of the current into the total resistance, R, of the circuit:

$$\text{Total electrical energy} = \frac{C^2\,R}{746} \text{ H. P.} \ldots\ldots\ldots\ldots (3).$$

The internal resistance of a direct circuit machine is the sum of the resistances of its armature and field magnets, and the current strength is the same in the armature, field and external circuit.

The internal resistance of a derived circuit dynamo consists of the resistance of its armature alone, as the field magnets are in parallel circuit with the external resistance. The current in the armature of a derived circuit machine is, therefore, equal to the sum of the currents in the field and external circuits.

Thus, with a direct circuit dynamo, if r represents the external resistance and r_1 the internal,

$$\text{Total electrical energy} = \frac{C^2\,r}{746} + \frac{C^2\,r_1}{746} \text{ H. P.} \dots\dots\dots\dots\dots (4).$$

The first term, $\frac{C^2\,r}{746}$ H. P., is the energy expended in the external circuit, and the second, $\frac{C^2\,r_1}{746}$ H. P., is the energy appearing in the dynamo.

Similarly with a derived circuit dynamo, if r, r_1 and r_2 represent the resistances of the external circuit, armature and field respectively, and C_1, C and C_2 the corresponding currents (remembering that $C = C_1 + C_2$),

$$\text{Total electrical energy} = \frac{C_1^2\,r}{746} + \frac{C_2^2\,r_2}{746} + \frac{(C_1 + C_2)^2\,r_1}{746} \text{ H. P.} \dots (5)$$

$$= \frac{C_1\,E}{746} + \frac{C_2\,E}{746} + \frac{(C_1 + C_2)^2\,r_1}{746} \text{ H. P.} \dots\dots (6).$$

In this case $\frac{C_1\,E}{746}$ H. P. is the energy appearing in the external circuit, $\frac{C_2\,E}{746}$ H. P., and $\frac{(C_1 + C_2)^2\,r_1}{746}$ H. P. being the energy absorbed by the dynamo in the field and armature respectively.

The efficiency of a generator is the ratio of the total electrical energy developed (2) to the amount of energy expended in driving the dynamo. The duty or electrical efficiency of a generator is the ratio of the total electrical energy developed to the energy expended in turning the armature in the magnetic field (1). The commercial efficiency of a generator is the ratio of the electrical energy which appears in the external circuit (6) to the total energy required to drive the machine. Thus, if the energy required to turn the armature in the magnetic field is W horse power, and the total energy applied to the armature pulley is P horse power,

$$\text{Efficiency} = \frac{\text{Total electrical energy}}{\text{P}} = \frac{\text{C E}}{746\ \text{P}} \ldots\ldots\ldots\ldots(7),$$

$$\text{Electrical efficiency} = \frac{\text{Total electrical energy}}{\text{W}} = \frac{\text{C}^2\ \text{R}}{746\ \text{W}} \ldots\ldots\ldots(8),$$

$$\text{Commercial efficiency} = \frac{\text{Electrical energy in external circuit}}{\text{P}} = \frac{\text{C}_1\ \text{E}}{746\ \text{P}} \ldots(9).$$

The energy expended in the external circuit is not wholly utilized in the lamps, as part of it is wasted in overcoming the resistance of the conductors. The amount so wasted is proportional to the resistance of the conductors, so that if the latter, for example, is 10 per cent. of the total resistance of the external circuit, the amount of energy wasted as heat in the conductors will be 10 per cent. of the total energy expended in the external circuit.

Let n represent the number of lamps in a circuit and r the resistance of each lamp, R being the resistance of the conducting wires; then, when the lamps are in series, as in the arc system, the portion of the total energy, p, expended in the external circuit, which appears in the lamps, will be

$$p\,\frac{n\,r}{\text{R} + n\,r} \ldots\ldots\ldots\ldots\ldots\ldots(10),$$

and the portion lost in heating the conductors will be

$$p\,\frac{\text{R}}{\text{R} + n\,r} \ldots\ldots\ldots\ldots\ldots\ldots(11).$$

When the lamps are in multiple circuit, as in the ordinary incandescent system, the portion of the total energy, p, in the external circuit, which is utilized in the lamps, is

$$p\,\frac{\frac{r}{n}}{\text{R} + \frac{r}{n}} = p\,\frac{r}{n\,\text{R} + r} \ldots\ldots\ldots(12),$$

and the portion wasted in the conductors is

$$p \frac{R}{R + \frac{r}{n}} = p \frac{n\,R}{n\,R + r} \text{ ....(13),}$$

$\frac{r}{n}$ being the joint resistance of the lamps.

The energy expended in a single lamp is equal to

$$c\,e \text{ watts} = \frac{c\,e}{746} \text{ H. P...........(14),}$$

where c is the current flowing through the lamp, and e is the electro motive force at its terminals.

If the lamp is placed in a photometer and its average illuminating power measured and found to be i candles, then the energy expended per candle will be

$$\frac{c\,e}{i} \text{ watts.......................(15),}$$

and the number of such lamps per electrical horse power will be

$$\frac{1}{\text{Horse power per lamp}} = \frac{746}{c\,e} \text{.......(16).}$$

DIRECT CALCULATION OF ELECTRICAL ENERGY.

From Calorimeter Test.—When the strength of a current has been measured by the calorimeter method (page 847), the amount of energy, p, appearing in the calorimeter may be calculated by the following formula, viz.:

$$p = \frac{W\,T\,772}{t} \text{ ft. lbs.........(17),}$$

where W is the weight of water in pounds, T its rise in temperature in degrees Fahrenheit, and t the time in seconds during which the current flowed. The total amount of energy appearing in the circuit will be equal to

$$P = p\,\frac{R}{r} \text{ ft. lbs.} = \frac{W\,T\,R\,772}{r\,t} \text{ ft. lbs....(18),}$$

where r represents the resistance of the calorimeter wire, and R is the total resistance of the circuit (including calorimeter).

Tests of Working Circuits.—In arc light circuits, where the lamps are in series, the current strength is kept constant and the electro motive force is increased or diminished as lamps are cut in or out of circuit. In order to detect any change in the strength of the current, it is sufficient to keep an ammeter in the circuit. When there is any deviation from the proper deflection, caused by a change in the number of lamps, the electro motive force should be altered until the required deflection is restored.

Fig. 540 shows a direct circuit dynamo supplying a number of arc lamps, L L, in series; the strength of the current flowing through the circuit is measured by the ammeter G.

In incandescent light circuits, where the lamps are burned in parallel circuit, it is the electro motive force which is kept constant, the current strength varying with the number of lamps. To measure the electro motive force, it is only necessary to connect a voltmeter to the binding screws of the dynamo. When the deflection of the voltmeter varies from the normal, the dynamo should be adjusted until the standard deflection is obtained.

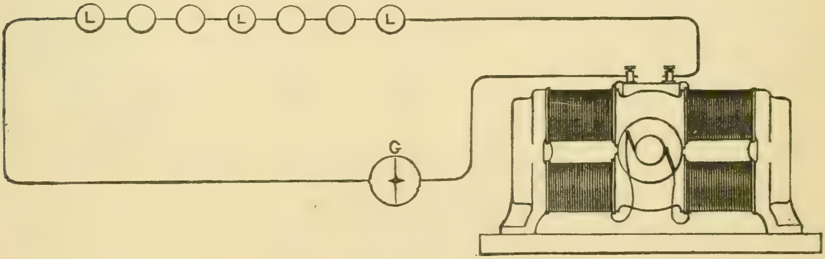

Fig. 540.

Fig. 541 shows a derived circuit dynamo supplying a number of incandescent lamps, L L, in parallel circuit. The electro motive force at the terminals of the dynamo is measured by the voltmeter G.

Many electric light systems have automatic devices for regulating the electro motive force and current strength; but it is always desirable to continuously measure both, as just described, whatever regulating devices may be employed.

Lamp Measurements.—The resistance of a lamp while burning, commonly called its hot resistance, may be calculated from the formula,

$$r = \frac{e}{c} \dots\dots\dots\dots\dots\dots\dots(19),$$

where the letters have the same signification as in formula 14. In the case of an arc lamp, the application of formula 19 includes the value of the counter electro motive force of the arc in terms of resistance.

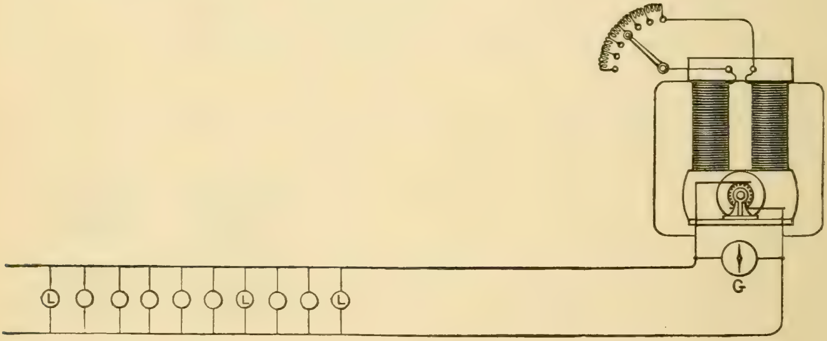

Fig. 541

To Measure the Efficiency of an Arc or Incandescent Lamp.—The lamp being placed in a photometer (fig. 542), where its illuminating power can be measured, it is connected through the current galvanometer, G, to the battery or current generator, E, and the circuit is then completed through the three point switch S_1. The electro motive force at the terminals of the lamp is measured by the potential galvanometer, P, which may be thrown in and out of circuit by means of the switch or key, K.

The hot resistance, r, of the lamp is measured by the method of substitution, for which purpose the adjustable wire resistance, or rheostat, R, is employed. As this rheostat may become heated during the test, a second three point switch, S_2, is provided, by means of which R may be connected to a Wheatstone bridge and its resistance accurately determined.

The connections having been arranged as above, switch S_1 is turned to the right and E adjusted, until the desired candle power, i, is obtained. The strength of the current, C, as indicated by the galvanometer, G, is now observed, and key, K, closed long enough to note the electro motive force, e, at the terminals of the lamp, as measured by the voltmeter, P.

The rheostat is now substituted for the lamp by turning S_1 to the left, S_2 being already on the right contact, and adjusted until the current strength is exactly equal to C as before. The resistance of R is now accurately measured by the Wheatstone bridge, to which it may be connected by turning switch S_2 to the left; the value thus obtained is equal to the hot resistance of the lamp—that is, $r = R$. The efficiency of the lamp may now be calculated by means of the preceding formulas, thus:

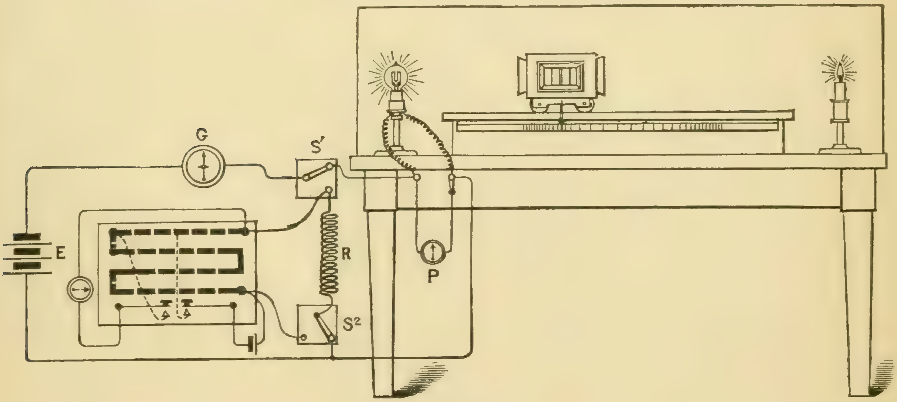

Fig. 542.

Energy expended in lamp (14) $= C\,e$ **watts.**

Energy per candle.......(15) $= \frac{C\,e}{i}$ **watts.**

Lamps per H. P.........(16) $= \frac{746}{C\,e}$

And as C e and r have been independently measured, the following checks may be applied, viz.:

$\frac{e}{C}$ should be equal to r
$e\,C$ " " " $C^2 r$.

TO MEASURE THE HOT RESISTANCE OF A LAMP.

Method of Equal Potentials.—An adjustable resistance, R (fig. 543), is connected in circuit with the lamp, L, whose resistance, r, is to be measured. One end of each of the two coils of a differential galvanometer, G, is connected to the junction of L and R. The remaining ends of the two coils of the galvanometer are connected, one to the opposite terminal of the lamp and the other to the opposite side of the resistance. The resistance, R, is now adjusted until the needle of the galvanometer remains at zero, and when this is accomplished

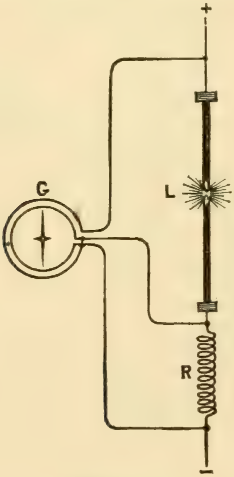

Fig. 543.

$$r = R.$$

For measuring arc lamps, R need not have more than three or four ohms resistance. It should be made of very thick wire and be capable of adjustment to a small fraction of an ohm.

The Weston ribbon rheostat (page 828) is suitable for this purpose.

To measure an incandescent lamp by the above method, R should have a resistance greater than that of the lamp, and the wire should be of such a diameter as to be capable of carrying the current required by the lamp without appreciable heating.

It is evident that two ordinary galvanometers could be substituted for the differential galvanometer in the above test, and if this was done, R would have to be adjusted until the current strength was the same in both galvanometers.

The potential method and method of substitution, as described above, offer, perhaps, the most satisfactory means of measuring with a rheostat the hot resistance of an arc lamp, which, of course, includes the resistance equivalent of the counter electro motive force of its arc.

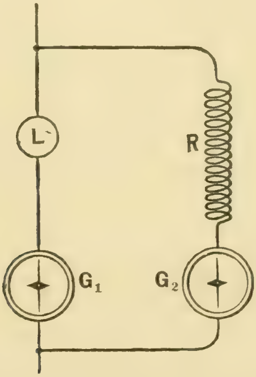

Fig. 544.

The following methods are applicable to the measurement of the resistance of an incandescent lamp while burning, but are not suitable to arc lamps, owing to their unsteadiness and the difficulties arising from shunting the strong currents which they usually require.

Differential Method.—The current galvanometer, G_1. fig. 544, is in circuit with the lamp, L, whose resistance, r, is required.

Connected in derived circuit around G_1 and L is a second galvanometer, G_2, and variable resistance, R. This latter is adjusted until the current strength as indicated by G_1 and G_2 are equal, when

$$r = \text{R ohms.}$$

The two coils of a differential galvanometer may be substituted for G_1 and G_2, in which case R should be adjusted until the needle of the galvanometer stands at zero.

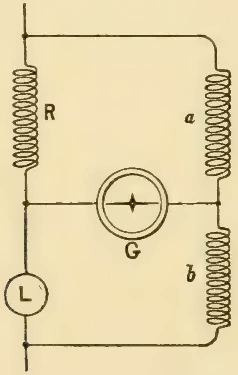

Fig. 545.

Bridge Method.—The lamp, L, fig. 545, whose resistance, r, is to be measured, is in circuit with an adjustable resistance, R. In derived circuit around L and R are the two resistances a and b. One terminal of a galvanometer, G, is connected to the junction of L and R, and the other terminal is connected to the junction of a and b. R is now adjusted until the needle of the galvanometer remains at zero, when

$$r = \text{R}\,\frac{b}{a}\ \text{ohms,}$$

and if $a = b$
$$r = \text{R ohms.}$$

Any sensitive galvanometer can be employed for this test, and to protect it from strong currents it may be shunted until a rough balance is obtained.

Shunts.—When strong currents are to be measured the employment of shunts is to be avoided if possible, as the unequal heating of the shunt wire and galvanometer coil may prove a source of error. It sometimes happens, however, that the range of the galvanometer at hand is not sufficiently great to meet the demands, and it becomes necessary to resort to a shunt.

If a current galvanometer having G ohms resistance is shunted by a wire of s ohms resistance, and the strength of the current which passes through the galvanometer is c ampères, the total strength, C, of the current will be

$$C = c\frac{G + s}{s} \text{ ampères,}$$

and if the constant of the galvanometer was k, the constant, k_1, of the shunted galvanometer will be

$$k_1 = k\frac{G + s}{s.}$$

The multiplying power of any shunt is equal to

$$\frac{G}{s} + 1.$$

To prepare a shunt having a definite multiplying power n, its resistance must be

$$S = \frac{G}{n - 1.}$$

The resistance of a shunted galvanometer is

$$\frac{G\,s}{G + s} \text{ ohms.}$$

To increase the range of measurement of a voltmeter an extra resistance may be added to it; that is to say, connected in the circuit with it. If the resistance added is equal to the resistance of the voltmeter, the constant of the latter will be doubled. If the constant of the voltmeter is equal to k, the addition of r_1 ohms will increase the constant to

$$k_1 = k\frac{r + r_1}{r_1}$$

where r is the resistance of the voltmeter and k_1 its new constant.

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Dynamo-electricity: its generation, application, transmission, storage and measurement. By George B. Prescott. With 545 illustrations. New York, D. Appleton, 1888.
xii, 867p. illus., fold. plates. 22cm.

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